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POINTWISE BI-SLANT LIGHTLIKE SUBMANIFOLDS OF INDEFINITE NEARLY KÄHLER MANIFOLDS

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ABSTRACT. In this paper, we introduce the notion of pointwise bi-slant lightlike submanifolds of an indefinite nearly Kähler manifold and provide a characterization theorem for the existence of these submanifolds. Following this, we provide a non-trivial example of pointwise bi-slant lightlike submanifolds of indefinite nearly Kähler manifolds and then derive some conditions for the distributions associated with this class of submanifolds to be involutive. Further, we provide a characterization for a pointwise bi-slant lightlike submanifold of an indefinite nearly Kähler manifold to be a bi-slant lightlike submanifold and investigate the geometry of totally umbilical pointwise bi-slant lightlike submanifold of an indefinite nearly Kähler manifold. Finally, we obtain necessary and sufficient conditions for foliations determined by distributions on pointwise bi-slant lightlike submanifolds of an indefinite nearly Kähler manifold to be totally geodesic.

Keywords: r-lightlike submanifold, Metric connection, Slant distribution, Bi-slant lightlike submanifold.

2020 Mathematics Subject Classification: 53B30, 53B25, 53B35.

1. INTRODUCTION

Chen [4, 5] introduced the notion of slant submanifolds of Kähler manifolds as a generalization of holomorphic and totally real submanifolds. Following this, Lotta [15, 16] introduced and studied concept of slant submanifolds in contact manifolds. Further, Carbrerizo et al.

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Adsorption Efficacy of Silver Nanoparticles Synthesized Using Wintergreen Plant Extract: A Green Approach to Dye Removal

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Abstract—This study uses wintergreen (*Gaultheria procumbens*) plant extract as a reducing agent in a green synthesis technique to create silver nanoparticles (AgNPs). Numerous analytical methods, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), UV-visible spectroscopy, and zeta potential analysis, were used to characterize the synthesized AgNPs. The results revealed the successful synthesis of AgNPs with an average size of approximately 25 nm and a face-centered cubic (FCC) crystalline structure. Furthermore, the synthesized AgNPs effectively removed direct yellow 4 (DY4) dye from aqueous solutions, displaying a maximum adsorption capacity of 92 mg/g. The adsorption kinetics of DY4 on AgNPs followed the pseudo-second-order model, indicating that chemisorption mechanisms predominantly govern the adsorption process. Additionally, the adsorption isotherms of DY4 on the surface of AgNPs adhered closely to the Langmuir isotherm model, suggesting monolayer adsorption on the uniform surface of AgNPs through strong adsorbate-adsorbent interactions. Moreover, the AgNPs demonstrated promising potential for reusability, as evidenced by the retention of approximately 97% adsorption efficiency even after undergoing four consecutive adsorption-desorption cycles. This highlights the robustness and durability of the AgNPs as effective adsorbents for wastewater treatment applications.

Keywords: adsorption, silver nanoparticles, plant extract, wintergreen plant, langmuir isotherm model, direct yellow 4

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INTRODUCTION

In recent years, the exploration of eco-friendly and sustainable solutions for various environmental and biomedical applications has gained significant momentum [1, 2]. Among these, the utilization of silver nanoparticles (AgNPs) derived from medicinal plant extracts has emerged as a promising avenue, offering dual benefits in terms of biological properties and wastewater dye removal [3, 4]. This introduction delineates the rationale behind exploring AgNPs synthesized from medicinal plant extracts, highlighting their potential as multifunctional agents for environmental remediation and biomedical applications [5–7]. The escalating concerns over environmental degradation and the deleterious effects of synthetic compounds on ecosystems and human health have underscored the urgency for eco-friendly and sustainable alternatives. Conventional methods for environmental remediation often involve the use of chemicals and processes that can exacerbate pollution and pose health risks [8, 9]. Hence, there is a pressing need to explore green and environmentally benign approaches for addressing pollution and improving environmental quality [10].

Conventional techniques for creating nanoparticles frequently call for dangerous chemicals and energy-intensive procedures, contributing to environmental degradation and posing risks to human health. Conversely, green nanotechnology focuses on building ecologically friendly methods for synthesizing nanoparticles from sustainable resources [11–13], such as plant extracts. By harnessing the phytochemicals present in medicinal plants, green synthesis provides a sustainable alternative to the basic principles of

eco-friendly manufacturing and environmental stewardship [14–16]. Medicinal plants have been revered for centuries for their therapeutic properties, owing to the diverse array of bioactive compounds present in their extracts. *Gaultheria procumbens*, commonly known as wintergreen, is one such medicinal plant known for its rich phytochemical profile, including phenolic compounds and flavonoids [17]. These bioactive constituents possess potent biological properties, making *Gaultheria procumbens* an ideal candidate for the synthesis of AgNPs with enhanced biological activity [18, 19]. Because of their distinct physicochemical characteristics and multipurpose uses, silver nanoparticles have become attractive options for medicinal and environmental applications. In addition to their well-documented antimicrobial activity, AgNPs exhibit remarkable biological properties attributed to their high surface area-to-volume ratio and surface plasmon resonance [20, 21]. These nanoparticles demonstrate scavenging activity against reactive oxygen species (ROS) and free radicals, thereby attenuating oxidative stress and oxidative damage in biological systems [22]. The textile industry is one of the largest contributors to water pollution globally, primarily due to the discharge of dye-containing wastewater into water bodies [23]. Synthetic dyes used in textile manufacturing pose significant environmental hazards, including water contamination, disruption of aquatic ecosystems, and adverse effects on human health [24–28]. Conventional wastewater treatment methods often fall short of effectively removing these recalcitrant dyes, necessitating the development of alternative strategies for dye remediation [29, 30]. The synergy between the biological properties of AgNPs and their efficacy in wastewater dye removal presents a unique opportunity for developing multifunctional materials with dual benefits [31, 32]. The literature on the synergistic potential of AgNPs, which are derived from medicinal plants for dye removal efficacy in a single material is still seriously lacking.

By synthesizing AgNPs from the medicinal plant *Gaultheria procumbens* and thoroughly examining their ability to remove dye contaminants from wastewater, this study fills a unique gap in the literature. It comprehensively investigates the functionality of AgNPs, offering a novel solution for environmental applications, while most current research focuses on their ability to remove dyes in isolation. By detailing their dye adsorption properties, this study presents new insights on how green-synthesized nanoparticles may contribute to environmentally responsible and sustainable solutions for cleanup. Our goal with this innovative integration is to provide a comprehensive solution that could enhance the effectiveness of existing wastewater treatment technologies and offer a sustainable alternative to biological systems.

EXPERIMENTAL

Materials and Chemicals

Silver nitrate of analytical grade ($AgNO_3$, purity 98%), sodium hydroxide, hydrochloric acid and direct yellow 4 were procured from Merck India and employed without any pre-treatment. To make the dye solutions, the powder was dissolved in deionized water and subsequently subjected to agitation on an orbital shaker for 30 min. No additional purification steps were undertaken for any of the reagents. Deionized water served as the solvent throughout the investigation.

Plant Collection and Extraction Preparation

Fresh wintergreen stems of *Gaultheria procumbens* were collected in July and August 2023 from their native habitat at Shillong Peak in Meghalaya, located at 1.830 m above sea level (25.576516° N, 91.886841° E). After collection, the stems were carefully cleaned with deionized distilled water, sliced into small pieces, and allowed to air dry at room temperature. They were then thoroughly rinsed using both tap and double-distilled water and sun-dried. Once dried, the stems were ground into a fine powder and stored away. Next, approximately 30 g of finely chopped stems were cooked for 40 min in 200 mL of deionized distilled water in a round-bottom flask. After cooling, the mixture was filtered through Whatman No. 1 filter paper, and the resulting filtrate was reserved for silver nanoparticle (AgNPs) production without any further processing.

Fourier-transform infrared spectroscopy (FTIR) and UV-vis spectroscopy investigations were conducted to determine the properties of the synthesized material. Notable phytochemicals such as phenolic compounds, flavonoids, tannins, and terpenoids as reported earlier [18, 19] identified in the extract included gallic acid and tannins, recognized for enhancing the stability of nanoparticles and their biological efficacy, as well as quercetin and catechin, powerful flavonoids with robust biological and metal-reducing properties, and methyl salicylate, the primary component known for its anti-inflammatory and biological benefits. These bioactive compounds acted as both stabilizing and reducing agents, which was crucial for the environmentally friendly production of AgNPs [18, 19].

Silver Nanoparticle Synthesis

The green synthesis procedure, as previously outlined with some modification, was executed for the preparation of silver nanoparticles (AgNPs) [33]. Notably, an extract of wintergreen plant (EWGP) was employed as the reducing agent instead of conventional choices like sodium borohydride, chosen for its favourable environmental and medicinal attributes.

Initially, a 25 mM stock solution of silver nitrate ($AgNO_3$) was prepared. Subsequently, 100 mL of this stock solution was gradually mixed with the extract until the medium reached half dilution, effectively reducing the concentration of Ag^+ ions. After that, the reaction mixture was swirled at room temperature until the color of the solution changed noticeably. Following completion of the reaction, centrifugation at 6000 rpm for 50 min facilitated the separation of nanoparticles from residual components. The resulting nanoparticle precipitate was redispersed in deionized water and subjected to secondary centrifugation in ethanol to eliminate any remaining biomass. Finally, the nanoparticles were obtained after vacuum drying and then used for further analysis.

Characterisation

The investigation encompassed a comprehensive array of analytical techniques to thoroughly characterize the synthesized materials. UV–vis spectroscopic analysis was meticulously performed employing a Lambda 750 (Perkin-Elmer) UV–vis spectrophotometer, ensuring precise determination of absorbance across a broad spectrum ranging from 200 to 800 nm, with a remarkable resolution of 1 nm. Fourier transform infrared (FTIR) spectra were meticulously acquired utilizing a cutting-edge Thermo-Fisher NICOLET IS50 FTIR spectrophotometer. This analysis was conducted employing KBr pellets at a controlled moderate temperature, with a scan rate at 4 cm^{-1} s^{-1}, facilitating detailed examination of functional groups and chemical compositions. Morphological and elemental analyses were carried out through Scanning electron microscopy (SEM) measurements and Energy-dispersive X-ray spectrometry (EDX) analysis, utilizing a JEOL Japan JSM 6610LV microscope operated at accelerating voltages of 10 and 15 kV, ensuring precise characterization of surface features and elemental distributions. Transmission electron microscopy (TEM) measurements were conducted employing a Tecnai G2 20 (FEI) S-Twin field emission electron microscope, providing high-resolution images for detailed examination of nanostructures and particle size distribution. X-ray diffraction (XRD) analysis, crucial for elucidating the crystalline structure, was meticulously performed utilizing a Rigaku SmartLab spectrometer with Cu-$K\alpha$ radiation, ensuring accurate determination of crystallographic information.

Statistical Analysis

The data underwent analysis utilizing SPSS 22.0 software. IC_{50} values were determined *via* equations for the best-fitted line derived from linear regression statistics utilizing the least squares method. After that, post-hoc Tukey's tests and one-way analysis of variance (ANOVA) were used to compare treatment means.

Zero-Point Charge (ZPC)

The determination of the zero-point charge (ZPC), denoted as the pH at which the surface charge of AgNPs attains neutrality (pH_{zpc}), was conducted employing the well-established pH drift method [34], renowned for its accuracy and reliability. Initially, 10 mL aliquots of the silver nanoparticle solution were dispensed into nine separate vials. The pH of each vial was adjusted across the range of 1 to 13 utilizing either 1 M NaOH or 1 M HCl acid solutions. Subsequently, all vials were allowed to equilibrate at ambient temperature for a period of 24 h to ensure the stabilization of pH levels. Following this stabilization period, the final pH of each vial was precisely measured, juxtaposing it against the initial pH value. The variation between the initial and final pH values for each vial was graphically represented. Notably, the intersection point of this plotted curve with both the initial pH and the difference between initial and final pH lines delineates the pH_{zpc}, thus indicating the pH at which the net charge on the AgNPs surface becomes neutral. This methodological approach ensures accurate determination of the crucial pH_{zpc} parameter, essential for understanding the surface chemistry and stability of AgNPs.

Adsorption of Direct Yellow 4 on AgNPs

Using a batch procedure, the adsorption behaviour of AgNPs was examined. The dye solution was made by dissolving a 0.0010 g sample of direct yellow 4 (DY4) dye in 100 mL of deionised water, and it was then kept at room temperature in the dark. Using 0.1 g of AgNPs as the adsorbent, the effects of several factors were investigated, including dye concentration (10–100 mg/L), contact duration (5–120 min), pH (1–13), and temperature (403–418 K). 50 mL of the dye solution was added to a 100 mL beaker containing AgNPs, and the mixture was agitated at 200 rpm to perform adsorption. Following the reaction, the mixture was filtered, and UV–vis spectroscopy was used to measure the amount of dye that remained at 400 nm. The adsorption percentage and the amount of dye adsorbed at time (t) were calculated using the following Eqs. (1) and (2):

$$\text{Adsorption Percentage}\,(\%) = \frac{(C_i C_t)}{C_i} \times 100, \qquad (1)$$

$$q_t = \frac{(C_i C_t)V}{m}, \qquad (2)$$

where, q_t represents the amount of DY4 adsorbed per unit mass of the adsorbent (mg/g), C_i is the initial MB concentration (mg/L), C_f is the final DY4 concentration (mg/L), C_t is the residual concentration at time t,

V denotes the volume of DY4 solution (mL), and m signifies the mass of the adsorbent (g).

Adsorption Isotherms

Initial dye concentrations ranged from 10 to 100 mg/L, and batch adsorption isotherm tests were carried out at a constant pH of 4 at 408 K. 50 mL of the appropriate dye solution was combined with 0.1 g of AgNPs for each trial. After 60 min of agitation at 200 rpm, the mixture was quickly chilled in an ice bath to prevent further adsorption. The concentration of remaining dye in the supernatant was measured using UV–vis spectroscopy at the maximum absorbance wavelength of 400 nm after dye solutions were separated by centrifugation at 5000 rpm for 20 min. This process made it possible to thoroughly examine the adsorption behaviour at different dye concentrations.

Adsorption Kinetics

Under controlled circumstances (pH 4, temperature 408 K), the kinetics of dye adsorption onto AgNPs were investigated. 0.1 g of AgNPs were added to 50 mL of the dye solution (concentration: 10 mg/L), and the mixture was shaken at 200 rpm. Samples were taken out at regular intervals (5 to 120 min) and put right into a cold bath to stop any more reactions. After centrifuging the mixture for 20 min at 5000 rpm, the amount of dye left in the supernatant was determined using UV–vis spectroscopy at 400 nm, which was based on a standard calibration curve.

Adsorption Thermodynamics

At a constant pH of 4, the adsorption isotherms were examined at temperatures between 403 and 418 K. 50 mL of the dye solution was mixed with 0.1 g of AgNPs in each trial. To prevent further adsorption, the mixture was rapidly moved to an ice bath after being stirred for 60 min at 200 rpm. Centrifugation was used to separate the dye for 20 min at 5000 rpm, and UV-vis spectroscopy was used to determine the amount of dye that remained in the supernatant.

Nanomaterial Reusability

The study delved into the successive adsorption capabilities of AgNPs to assess its potential for reuse. In the initial cycle, 0.1 mg of AgNPs was introduced into a 50 mL solution of DY4 with a concentration of 10 mg/L. This mixture underwent agitation for 60 min, followed by the collection of AgNPs *via* centrifugation at 5000 rpm for 20 min. The collected nanoparticles were precisely washed with deionized water and methanol before being dried in an oven at 60°C. Subsequently, a 0.05% suspension was prepared from the dried AgNPs and utilized for cycle 1 in a UV cuvette. The remaining AgNPs were then repurposed for subsequent reactions conducted in the absence of light. This process was repeated for multiple cycles, with cycle nine serving as a checkpoint to evaluate the reusability of the AgNPs. Such experimentation sheds light on the potential of AgNPs for sustainable and cost-effective applications in various domains.

RESULTS AND DISCUSSION

Nanocomposite Design Strategy

The synthesis of AgNPs employing a green approach utilizing EGRP was achieved through a designed procedure [39]. EGRP extract was combined with silver nitrate aqueous solution at room temperature during this process. Remarkably, the manifestation of AgNPs was promptly discerned by the distinct colour alteration of the EGRP extract, transitioning from a yellow hue to a black colour within 30 min after the amalgamation of the solutions. Initially, the nanoparticle activation ensued, characterized by the reduction of Ag^+ ions to Ag^0, thereby instigating the nucleation of reduced silver atoms. This nucleation event precipitates the growth of a homogeneously structured AgNPs ensemble, concomitant with the progressive reduction of silver ions, consequently fostering the augmentation of thermodynamic stability within the nascent AgNPs. Subsequently, the stabilization of the AgNPs is arranged by the concerted action of phytochemical moieties inherent within the EGRP extract. These phytochemical entities function as efficacious capping agents, thereby mitigating the propensity for agglomeration among the AgNPs. Noteworthy is the characterization of this synthesis methodology as inherently eco-friendly, facile to execute, rapid in its kinetics, and operates under mild reaction conditions, thus encapsulating the pragmatic and sustainable synthetic strategy.

Characterisation of Silver Nanoparticles (AgNPs)

The investigation of surface morphology and size through transmission electron microscopy (TEM) and scanning electron microscopy (SEM), is crucial for understanding the properties and potential applications of biogenic silver nanoparticles [40]. SEM analysis of AgNPs synthesized using wintergreen plant extract revealed important insights into their morphology and size distribution. The SEM Figs. 1a–1c unveiled larger particles of AgNPs, suggesting aggregation induced by solvent evaporation during sample preparation. Additionally, particle size distribution was observed, with some particles reaching up to 60 nm with spherical shape (Fig. 1c). This aggregation phenomenon was further supported by the presence of smaller particles surrounding larger ones, indicating a coagulation process. TEM imaging provided complementary information, illustrating the spherical shape of AgNPs with an average size of approximately 15 nm

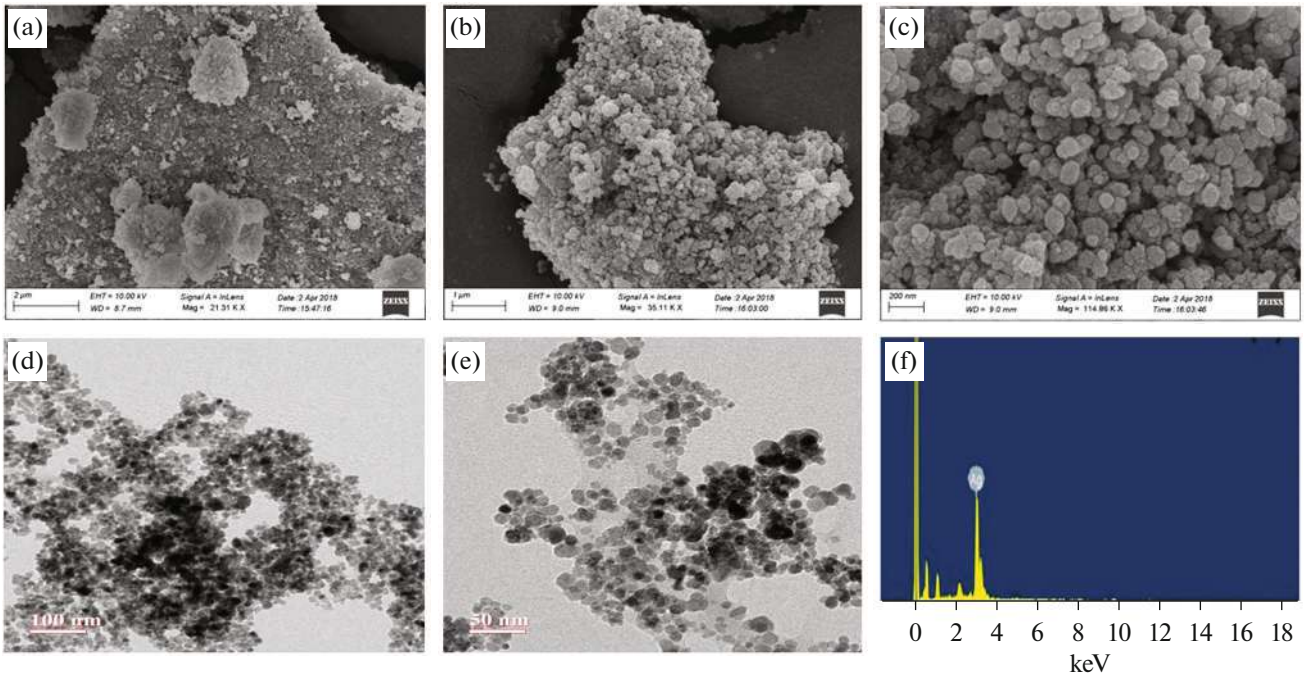

Fig. 1. SEM (a–c, 2 μ, 1 μ and 200 nm, respectively) and TEM (d–e, 100 and 50 nm) images of silver nanoparticles at different magnifications; (f) EDX spectrum of silver nanoparticles.

(Figs. 1d–1e). The size and shape of the synthesized AgNPs were confirmed by the TEM results, which showed good agreement with the SEM findings. The adsorption qualities of nanoparticles are significantly influenced by their size and shape. Understanding these characteristics is essential for optimizing the performance of AgNPs in various applications.

The elemental composition analysis was conducted *via* SEM equipped with EDX and subsequent energy dispersive [41]. X-ray spectroscopy (EDX) provided crucial insights into the formation of silver nanoparticles. The strong signals observed in the silver region (depicted in Fig. 1f) confirmed the presence of AgNPs, with characteristic absorption peaks indicative of surface plasmon resonance (SPR). Additionally, the involvement of silver as a capping agents from the plant extract was suggested by the EDX spectroscopy, which provided both quantitative and qualitative information about other elements present in the nanoparticles.

The UV-visible spectra analysis revealed a prominent peak of absorbance at 420 nm, exhibiting a progressive enhancement in intensity with prolonged incubation duration of silver nitrate with the plant extract (Fig. 2a) [42]. Concurrently, discernible peaks were identified at 420 nm, suggesting that silver nanoparticles have surface plasmon resonance. This observation strongly suggests an extracellular reduction of Ag^+ ions. Notably, previous research by Nestor et al. [43] has underscored the significance of absorbance around 430 nm as a hallmark feature of noble metal particles such as silver. The X-ray diffraction (XRD) analysis conducted in the range of data was gathered spanning from 30° to 80° of 2θ, with an incremental step of 0.0202°, ensuring comprehensive coverage of the sample's diffraction profile. In a rigorous comparative analysis, the resultant diffractogram (as depicted in Fig. 2b) was aligned with the standard reference powder diffraction card sourced from JCPDS file No. 04-0783 [44]. This scrutiny revealed distinct peaks at 2θ values of 38.2901°, 44.5583°, 64.8185°, and 77.4383°, unequivocally attributed to the presence of silver metal. These peaks corresponded continuously to the (*hkl*) values denoting the (111), (200), (220), and (311) planes of silver, affirming the crystalline structure of the face-centered cubic (FCC) characteristic of silver nanoparticles. Additionally, the diffractogram exhibited four supplementary peaks at 32.35°, 46.38°, 54.03°, and 57.66°, attributed to $AgNO_3$, implying residual quantities potentially unaltered during the reduction process. Subsequently, employing the Debye-Scherrer formula, the average crystalline size (*D*) of the silver nanoparticles was estimated, yielding a remarkable consensus of approximately 20 nm, reaffirming the homogeneity and structural integrity of the synthesized nanoparticles.

The biomolecular components that regulate the stabilisation and surface coating of silver nanoparticles derived from *Gaultheria procumbens* (wintergreen) plant extract were examined using FTIR spectroscopy. When closely examined, distinct peak patterns were found in both synthesised AgNPs, indicating the pres-

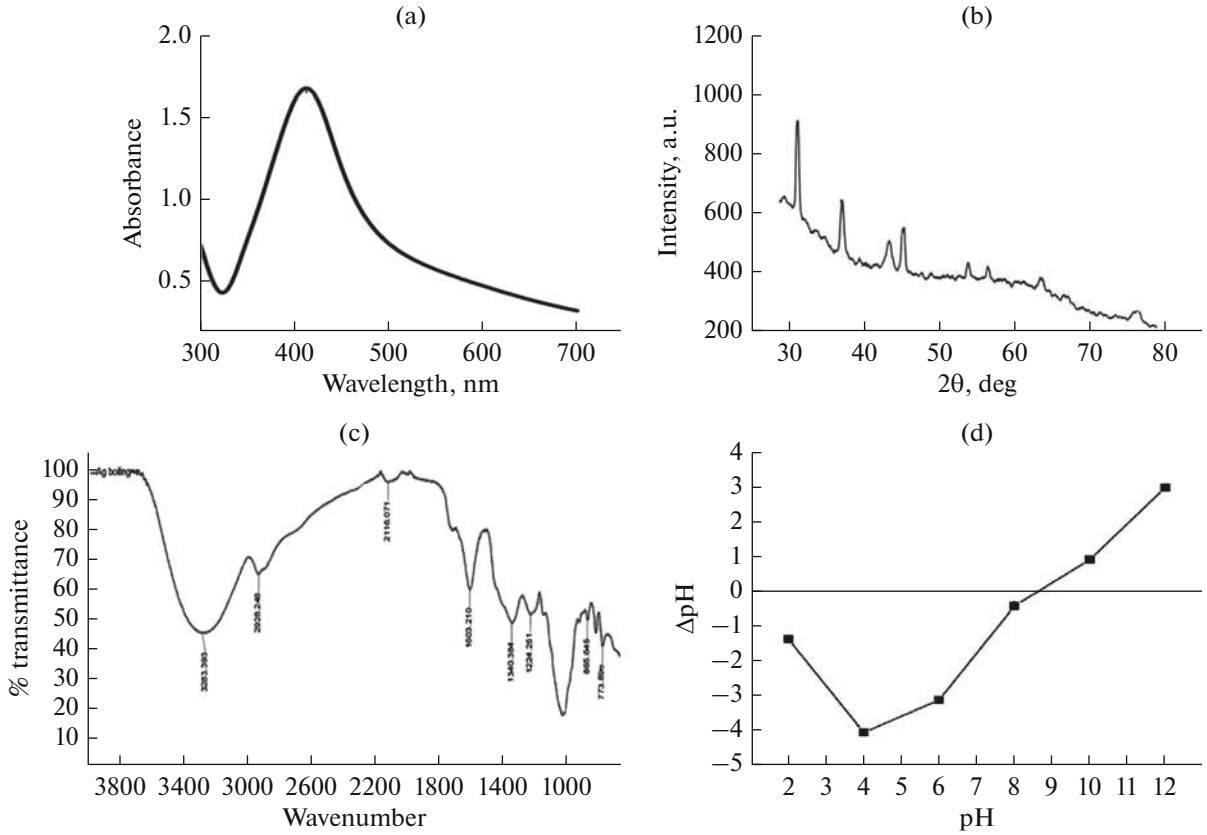

Fig. 2. UV-Visible (a), XRD (b), FTIR (c) and zero-point charge (d) spectra of AgNPs.

ence of phenolics, aliphatic/aromatic hydroxyl groups, and amino acids. Alkanes were represented by peaks at 2865 and 2933 cm^{-1}, which is in line with earlier studies (Fig. 2c). Notably, the 1611–1400 cm^{-1} range suggested aromatic ring existence. Primary/secondary amides and alkyl halides were indicated by peaks at 1109 cm^{-1} (OH groups) and 827 cm^{-1} (alkyl halides). These results were confirmed by extensive research on *G. procumbens*. These functional groups' attachment to AgNPs suggested that they played a part in metal ion reduction and encapsulation. Significantly, stretching vibrations were ascribed to the encapsulation-facilitating mediation of aliphatic/aromatic OH group repositioning by phenolic chemicals.

Because the plant extract came from a natural source, environmental factors like soil composition, climate, and harvesting conditions may cause minor differences in its composition. FTIR analysis was carried out on several batches of extract derived from various harvests to assess the repeatability of the extract's properties. The primary functional groups involved in AgNP production, specifically hydroxyl (–OH), carbonyl (C=O), and aromatic rings, were shown to be constant across batches, according to the spectral analysis. Even though there were slight differences in peak intensities, they had no appreciable effect on the extract's capacity to reduce and stabilize. This consistency implies that the green synthesis of AgNPs with extract from *G. procumbens* is repeatable, guaranteeing consistent nanoparticle generation with little change from batch to batch.

The pH level of the solution containing the substance to be adsorbed is critical in the process of adsorption since it impacts both the surface charge of the material adsorbing and the movement of the substance being adsorbed. According to the pH at the zero-point charge (pH_{pzc}), when the pH surpasses the pH_{pzc}, the surface charge of the material tends to be predominantly negative, while a net positive charge is observed when the solution's pH falls below the pH_{pzc}. For instance, in the case of AgNPs, depicted in Fig. 2d, the zero-point charge is noted at pH 8.6 on the surface of the AgNPs. Notably, this pH level exceeds the one where the adsorbent exhibits maximal adsorption. This suggests that the surface of AgNPs carries a positive charge, thereby exhibiting exceptional adsorption capabilities towards anionic dyes.

Adsorption Studies

Effect of pH and temperature. When using synthetic silver nanoparticles (AgNPs) for water treatment, the adsorption of direct yellow 4 (DY4) is significantly influenced by the pH level. The dye's interaction with

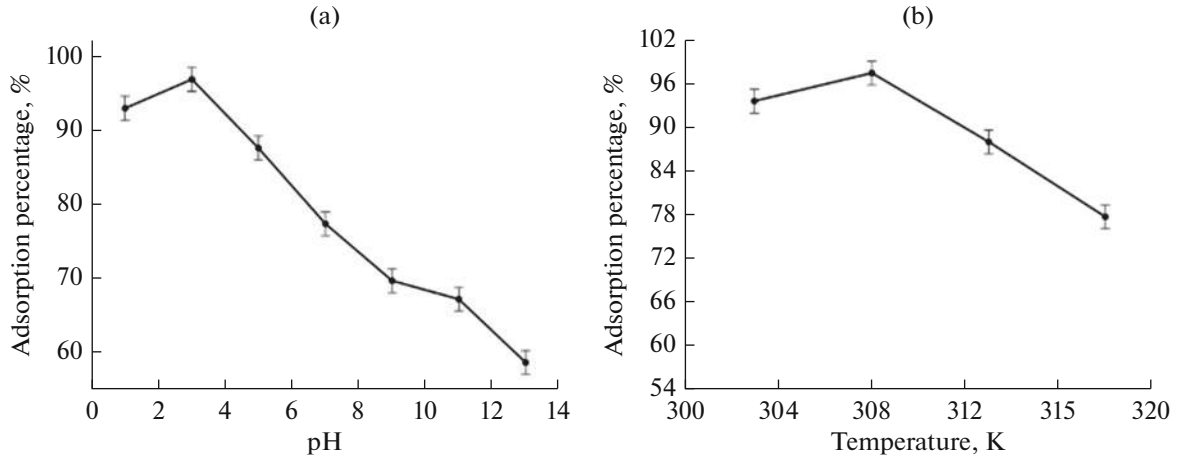

Fig. 3. (a) The effect of pH on adsorption of DY4 dye by AgNPs. (b) The effect of temperature on the removal of DY4 dye onto AgNPs.

AgNPs is directly affected by its pH-dependent ionic state. At lower pH values (acidic conditions), DY4 predominantly exists in its protonated form, which results in less electrostatic attraction to the positively charged AgNPs, leading to decreased adsorption effectiveness. However, as the pH exceeds the zero-point charge (pH_{pzc}) of AgNPs (pH 8.6, as shown in Fig. 2d), the nanoparticles acquire a negative charge, enhancing the adsorption of the dye in its anionic form due to strong electrostatic interactions. By balancing electrostatic forces and hydrogen bonding interactions, the partial ionization of the dye increases its affinity for AgNPs, leading to optimal adsorption at pH 4. Beyond this pH, electrostatic repulsion causes excessive negative charge accumulation on both AgNPs and dye molecules, thereby reducing adsorption effectiveness.

The effect of temperature on the percentage of decolorization is shown in Fig. 3b. According to the study, the ideal temperature for dye degradation is 308 K. At lower temperatures, there is insufficient interaction between the negatively charged adsorbent and dye molecules. Conversely, raising the temperature above 308 K results in a significant decrease in dye adsorption. This decline can be attributed to the heightened kinetic energy of dye molecules, causing them to desorb from the adsorbent surface. Consequently, the maximum adsorption percentage is recorded at 308 K, indicating the critical role of temperature in optimizing dye removal efficiency.

Adsorption Kinetics

The pseudo-first order and pseudo-second order models developed by Lagergren were used to assess the adsorption kinetics. The pseudo-first-order model is described by Eq. (3), which shows that the difference between equilibrium and current adsorption capacity is directly proportional to the rate at which the bound absorbate changes with time. Conversely, Eq. (4) portrays the pseudo-second order model, suggesting that the adsorption process is governed by a rate-limiting step [45, 46].

$$\ln\left(q_e - q_t\right) = \ln q_e - K_1 t, \tag{3}$$

$$\frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{K_2 q_e^2}. \tag{4}$$

In this case, t denotes the time in minutes, while q_e and q_t stand for the adsorption capacity at equilibrium and at a certain time t (mg/g). Additionally, K_1 denotes the first-order rate constant (min^{-1}), and K_2 represents the second-order rate constant (g mg^{-1} min^{-1}). Parameters derived from Eqs. (3), (4) are summarized in Table 1. Comparing the regression coefficients, the pseudo-second order model outperformed the pseudo-first order model, yielding coefficients of 0.9797 for DY4 dye solutions, respectively, whereas the coefficients for the pseudo-first order model were 0.9374. Graphs illustrating the second-order kinetics displayed linearity (Figs. 4a–4b), with adsorption capacities closely aligning with experimental values (Fig. 4c). Overall, the kinetic data suggest that chemisorption and a rate-limiting step are crucial factors influencing dye adsorption on the adsorbent.

Adsorption Thermodynamics

The thermodynamic parameters ($\Delta G°$, $\Delta S°$ and $\Delta H°$) were employed to discern the nature of adsorption of direct yellow 4 dye on the Ag nanoparticles, determining whether the process is endothermic or exothermic and spontaneous or non-spontaneous. $\Delta G°$, $\Delta S°$ and $\Delta H°$ were computed using Eqs. (5) and (6) respectively:

$$\Delta G° = -RT \ln K_d, \tag{5}$$

Table 1. Kinetics parameters in the adsorption process of DY4 on AgNPs

Dyes	1st order			2nd order			Exp.
	q_e, mg g^{-1}	K_1, min^{-1}	r^2	q_e, mg g^{-1}	K_2, g mg^{-1} min^{-1}	r^2	q_e, mg g^{-1}
DY4	117.56	0.04	0.9374	89.56	0.00047	0.9797	92.98

Table 2. Thermodynamic parameters for DY4 dye onto Ag NNPs in the adsorption processes

Parameters	$\Delta H°$, kJ mol^{-1}	$\Delta S°$, J mol^{-1}	$\Delta G°$, kJ mol^{-1}			
Temperature	308 K	308 K	303 K	308 K	313 K	318 K
DY4	−2.822	−4.668	−1.408	−1.385	−1.361	−1.338

$$\ln K_d = \frac{\Delta S°}{R} - \frac{\Delta H°}{RT}. \quad (6)$$

Here, T is the temperature in Kelvin, R is the gas constant (8.314 J mol^{-1} K^{-1}), K_d (kJ mol^{-1}) is the distribution coefficient ($K_d = q_e/C_e$), $\Delta G°$ (kJ mol^{-1}) is the change in Gibb's free energy, $\Delta S°$ (J mol^{-1} K^{-1}) is the entropy change, and $\Delta H°$ (kJ mol^{-1}) is the enthalpy change at 308 K. Table 2 compiles all of the parameters that were obtained from these equations. The calculated values of $\Delta G°$ and $\Delta H°$ are negative, suggesting that the adsorption process is both spontaneous and exothermic. This emphasises the energy release and electrostatic interaction that take place when dye molecules adsorb onto the adsorbent's active regions in the absence of outside influences. Additionally, a decrease in disorder during the adsorption process after the contact between the dye molecules and the adsorbent is shown by a negative value of $\Delta S°$.

Adsorption Isotherm

The adsorption isotherm of the AgNPs was explored across varying initial concentrations of DY4 solutions, with all other parameters held constant. Various isotherm models were employed to elucidate the interaction nature between the adsorbent and adsorbate at equilibrium, as well as to determine the maximum adsorption capacity of the AgNPs for DY4 dye. Specifically, two equilibrium models, namely Langmuir and Freundlich, were utilized to analyze the experimental data using Eqs. (7) and (8) respectively:

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e}, \quad (7)$$

where C_e is the dye solution's equilibrium concentration, K_L (L/mg) is the Langmuir adsorption constant related to the binding site's affinity, and q_{max} and q_e (mg/g) are the adsorbent's maximum and equilibrium adsorption capacities.

$$q_e = K_F C_e^{1/n}. \quad (8)$$

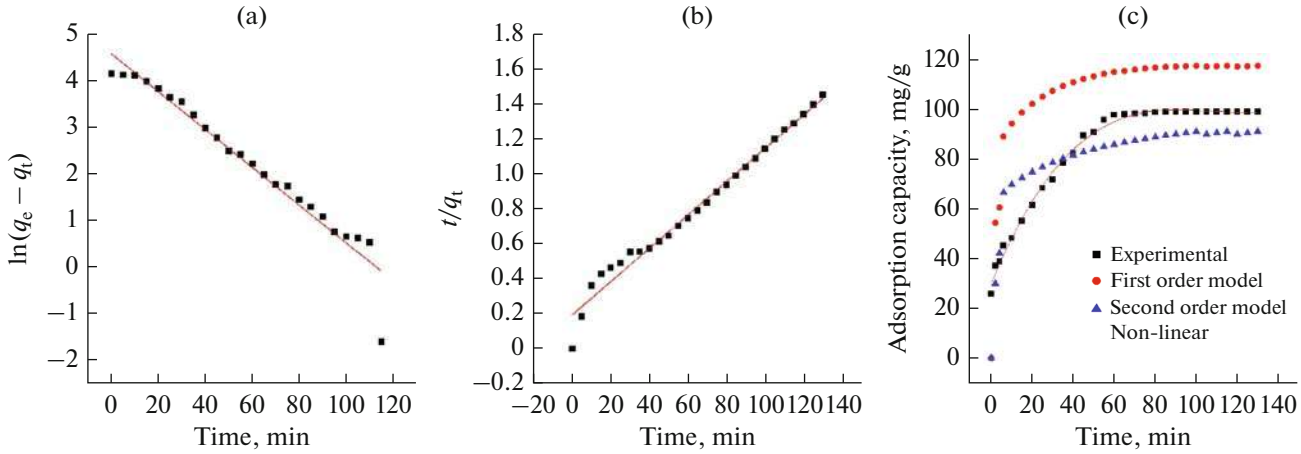

Fig. 4. Pseudo- first (a) and second-order (b) kinetic model for adsorption of DY4 on AgNPs. (c) Adsorption capacity for first and second order models.

Table 3. Isotherm parameters in the adsorption process

	Langmuir			Freundlich			Experimentally
	q_{max}, mg g^{-1}	K_L, L mg^{-1}	R^2	K_F, L mg^{-1}	N	R^2	q_m, mg g^{-1}
DY4	102.52	0.718	0.9707	3.96	1.21	0.8222	110.77

The adsorption capacity and intensity of the adsorbent are indicated by the Freundlich isotherm constants, K_F (L/mg) and n, respectively. With the values given in Table 3, the experimental findings were fitted to the Langmuir and Freundlich isotherm models for DY4 dye, as shown in Figs. 5a and 5b, respectively. In contrast to the Freundlich isotherm model (0.8222), the experimental data for DY4 dyes showed a superior match with the Langmuir isotherm model, as indicated by higher regression coefficients of 0.9707. This implies that monolayer adsorption plays a major role in the adsorption process. Additionally, based on the Langmuir model and experimental calculations for the corresponding dye solutions, the AgNPs' maximum adsorption capabilities were found to be 102.52 mg/g DY4 and 110.77 mg/g DY4, respectively (Fig. 5c).

Stability and Reusability of Adsorbent

The pivotal attributes of composite materials lie in their recyclability and stability, which serve as fundamental pillars in mitigating costs while upholding persistent and efficient catalytic performances, thus rendering them indispensable for practical applications in wastewater treatment. Utilizing silver nanoparticles in such composites not only ensures cost-effectiveness but also facilitates simple recovery owing to the abundance and easy sedimentation of this natural resource in aqueous dispersion. The reusability of dye adsorbents emerges as a critical criterion for assessing their efficacy in wastewater treatment endeavours. In the depicted study, the performance evaluation of a nanoparticle in removing DY4 from wastewater reveals intriguing insights. As illustrated in Fig. 6, across the initial five cycles, the adsorption capacity of DY4 fluctuated within a range of 97 to 95%. This nuanced fluctuation in adsorption could potentially be attributed to a combination of partial DY4 desorption and the loss of minute quantities of AgNPs during the washing process. Conversely, the shorter desorption duration observed might be indicative of a more efficient desorption process, possibly facilitated by reduced desorption time. Nevertheless, it becomes evident that the remarkable reusability of AgNPs underscores their promise in effectively eliminating various dye contaminants during wastewater treatment processes.

Comparison with Earlier Reported Work

As little work has done on DY4 dye, Table 4 provides comparison of our obtained result with published reports for the degradation performance of DY4 dye as organic pollutants at the indicated experimental conditions. Our study on biosynthesized AgNPs demonstrated a high adsorption capacity of 110.97 mg/g within 60 min at 308 K, providing an energy-efficient and environmentally friendly approach for direct yellow 4 (DY4) dye removal. Unlike advanced oxidation processes, this method does not require external energy input or stringent conditions, making it a cost-effective alternative. In contrast, the electro-Fenton (EF) process facilitated

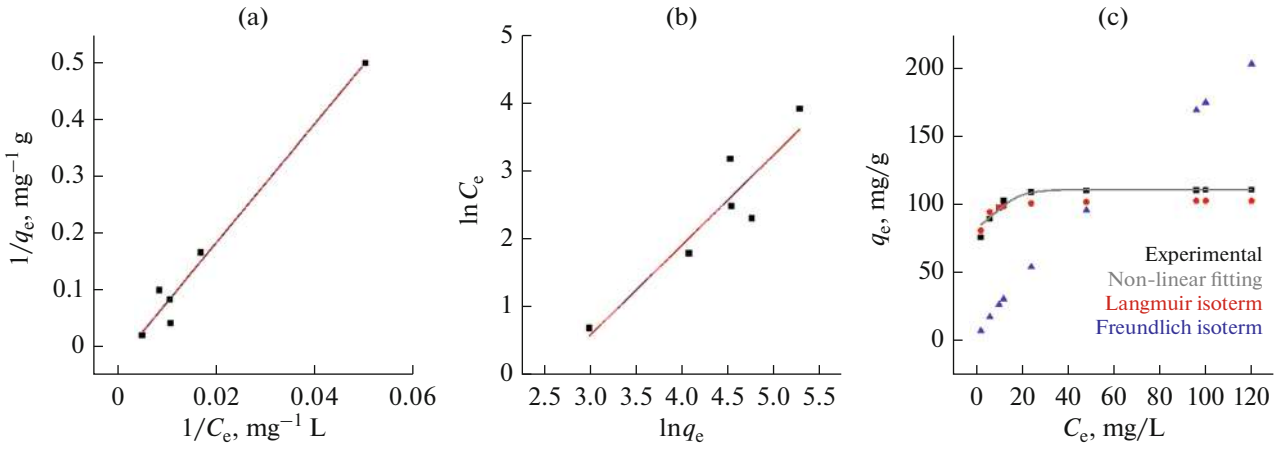

Fig. 5. Adsorption isotherm of DY4 dye on the AgNPs.

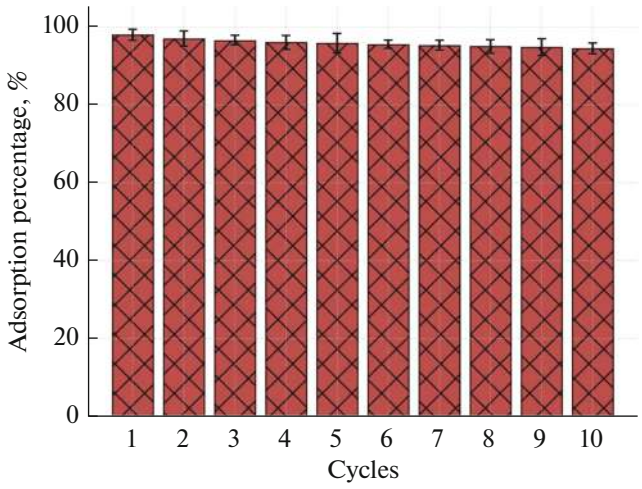

Fig. 6. Reproducibility of AgNPs with DY4 dye.

partial mineralization, meaning the dye was broken down into intermediate organic compounds rather than being fully degraded. This method required an acidic pH 3.0 and electrochemical input, making it more complex and resource-intensive. The Photo-electro-Fenton (PEF) and Photo-Assisted Electro-Fenton (PA-EF) processes achieved near-total mineralization of DY4 by integrating EF with UVA light, significantly enhancing degradation efficiency but demanding high energy input and controlled reaction conditions [47, 48]. Overall, our biosynthesized AgNPs-based adsorption method presents a sustainable and efficient approach for dye removal, particularly in scenarios where energy-intensive oxidation methods are impractical. However, while adsorption effectively removes the dye from solution, it does not degrade it into non-toxic byproducts, unlike Fenton-based methods, which ensure complete mineralization. Treatment goals, operational feasibility and environmental impact considerations should guide the choice between adsorption and oxidation.

CONCLUSIONS

In conclusion, wintergreen plant extract was used in the green synthesis of silver nanoparticles, which turned out to be a simple, environmentally responsible, and quick way to produce small particles. The synthesized AgNPs exhibited favourable characteristics including a spherical morphology, uniform size distribution and crystalline structure. The comprehensive characterization of AgNPs using various analytical techniques provided valuable insights into their structural and chemical properties. The adsorption capacity was notably influenced by parameters such as contact time, pH, temperature and dye concentration. Notably, the biosynthesized AgNPs exhibited superior adsorptive removal capacity for direct yellow 4 (DY4) dye, achieving a removal efficiency of 110.97 mg/g within a 60 min timeframe at 308 K. The Langmuir isotherm model demonstrated the best fit with a maximum monolayer capacity, indicating a chemisorption mechanism. Kinetic modelling revealed that the adsorption of DY4 dye onto AgNPs followed a pseudo-second-order reaction, further confirming the efficient adsorption process. The negative values of ΔG° and ΔH° indicated an exothermic spontaneous process at the interface of the adsorbent and adsorbate, with physisorption playing a significant role. Importantly, the material exhibited reusability, maintaining catalytic performance over nine cycles without significant degradation. Overall, this study contributes to the development of sustainable nanomaterials with promising applications in environmental remediation and healthcare.

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Table 4. Comparative data summarizing the removal efficiencies of direct yellow 4 (DY4) dye using various methods, including your study

Method	Mechanism	Removal Efficiency	Time, min	Conditions	Reference
Electro-Fenton (EF)	Advanced Oxidation ($^{\bullet}$OH radicals)	Partial mineralization	Not specified	pH 3.0, electrochemical process	[47]
Photo-Assisted Electro-Fenton (PA-EF)	EF followed by UVA illumination	Similar to PEF	Not specified	pH 3.0, sequential EF and UVA exposure	[47]
Photo-electro-Fenton (PEF)	EF + UVA light	Near-total mineralization	Not specified	pH 3.0, electrochemical + UVA light	[48]
Biosynthesized AgNPs	Adsorption	110.97 mg/g	60	308 K, no external energy input	Our study

Chemistry at Sri Venkateswara College, University of Delhi, New Delhi, India.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. Sadiku, E.R., Agboola, O., Ibrahim, I.D., et al., Synthesis of bio-based and eco-friendly nanomaterials for medical and BioMedical applications, in *Green Biopolymers and Their Nanocomposites, Materials Horizons: From Nature to Nanomaterials*, Singapore: Springer, 2019, pp. 283–312.
2. Verma, C., Verma, D.K., Berdimurodov, E., et al., Green magnetic nanoparticles: A comprehensive review of recent progress in biomedical and environmental applications, *J. Mater. Sci.*, 2024, vol. 59, no. 2, pp. 325–358. https://doi.org/10.1007/s10853-023-08914-5
3. Maillard, A.P.V.F., Jimenez, L.E., Álvarez, R.M.S., et al., Physicochemical and biological characterization and applications of silver nanoparticles obtained by green synthesis using *Cichorium intybus, Colloids Surf. A*, 2024, vol. 709, p. 136075. https://doi.org/10.1016/j.colsurfa.2024.136075
4. Albukhari, S.M., Ismail, M., and Akhtar, K., Catalytic reduction of nitrophenols and dyes using silver nanoparticles@cellulose polymer paper for the resolution of waste water treatment challenges, *Colloids Surf. A*, 2019, vol. 519, pp. 548–561. https://doi.org/10.1016/j.colsurfa.2019.05.058
5. Mitra, K., Biosynthesis of silver nanoparticles and their antimicrobial properties: A review on recent advances, *Asian J. Chem.*, 2022, vol. 34, no. 4, pp. 757–766. https://doi.org/10.14233/ajchem.2022.23525
6. Simon, S., Sibuyi, N.R.S., Fadaka, A.O., et al., Biomedical applications of plant extract-synthesized silver nanoparticles, *Biomedicines*, 2022, vol. 10, no. 11, p. 2792. https://doi.org/10.3390/biomedicines10112792
7. Amirthalingam, R. and Gunabalan, M., An insight into the insecticidal activity of green synthesized silver nanoparticles, *Colloid J.*, 2023, vol. 85, no. 5, pp. 854–870. https://doi.org/10.1134/S1061933X23600045
8. Roy, M. and Saha, R., 6 – Dyes and their removal technologies from wastewater: A critical review, in *Intelligent Environmental Data Monitoring for Pollution Management*, Academic Press, 2021, pp. 127–160. https://doi.org/10.1016/B978-0-12-819671-7.00006-3
9. Saravanan, A., Kumar, P.S., Jeevanantham, S., et al., Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development, *Chemosphere*, 2021, vol. 280, p. 130595. https://doi.org/10.1016/j.chemosphere.2021.130595
10. Rajmohan, K.S., Chandrasekaran, R., and Varjani, S., A review on occurrence of pesticides in environment and current technologies for their remediation and management, *Indian J. Microbiol.*, 2020, vol. 60, pp. 125–138. https://doi.org/10.1007/s12088-019-00841-x
11. Khan, F., Shariq, M., Asif, M., et al., Green nanotechnology: Plant-mediated nanoparticle synthesis and application, *Nanomaterials*, 2022, vol. 12, no. 4, p. 673. https://doi.org/10.3390/nano12040673
12. Kumar, J.A., Krithiga, T., Manigandan, S., et al., A focus to green synthesis of metal/metal based oxide nanoparticles: Various mechanisms and applications towards ecological approach, *J. Cleaner Prod.*, 2001, vol. 324, p. 129198. https://doi.org/10.1016/j.jclepro.2021.129198
13. Alqarni, L.S., Alghamdi, M.D., Alshahrani, A.A., et al., Green nanotechnology: Recent research on bioresource-based nanoparticle synthesis and applications, *J. Chem.*, 2022, vol. 2022, p. 4030999. https://doi.org/10.1155/2022/4030999
14. Ashraf, M.V., Pant, S., Khan, M.H., et al., Phytochemicals as antimicrobials: Prospecting Himalayan medicinal plants as source of alternate medicine to combat antimicrobial resistance, *Pharmaceuticals*, 2023, vol. 16, no. 6, p. 881. https://doi.org/10.3390/ph16060881
15. Sarasan, V., Kite, G.C., Sileshi, G.W., et al., Applications of phytochemical and in vitro techniques for reducing over-harvesting of medicinal and pesticidal plants and generating income for the rural poor, *Plant Cell Rep.*, 2011, vol. 30, pp. 1163–1172. https://doi.org/10.1007/s00299-011-1047-5
16. Phillipson, J.D., Phytochemistry and medicinal plants, *Phytochemistry*, 2001, vol. 56, no. 3, pp. 237–243. https://doi.org/10.1016/S0031-9422(00)00456-8
17. Ribnicky, D.M., Poulev, A., and Raskin, I., The determination of salicylates in Gaultheria procumbens for use as a natural aspirin alternative, *J. Nutraceuticals Funct. Med. Foods*, 2003, vol. 4, no. 1, pp. 39–52. https://doi.org/10.1300/J133v04n01_05
18. Michel, P. and Olszewska, M.A., Phytochemistry and biological profile of *Gaultheria procumbens* L. and wintergreen essential oil: From traditional application to molecular mechanisms and therapeutic targets, *Int. J. Mol. Sci.*, 2024, vol. 25, no. 1, p. 565. https://doi.org/10.3390/ijms25010565
19. Michel, P., Dobrowolska, A., Kicel, A., et al., Polyphenolic profile, antioxidant and anti-inflammatory activity of eastern teaberry (*Gaultheria procumbens* L.) leaf extracts, *Molecules*, 2014, vol. 19, no. 12, pp. 20498–20520. https://doi.org/10.3390/molecules191220498

20. Khan, M., Ahmad, F., Koivisto, J.T., et al., Green synthesis of controlled size gold and silver nanoparticles using antioxidant as capping and reducing agent, *Colloid Interface Sci. Commun.*, 2020, vol. 39, p. 100322. https://doi.org/10.1016/j.colcom.2020.100322
21. Sreelekha, E., George, B., Shyam, A., et al., A comparative study on the synthesis, characterization, and antioxidant activity of green and chemically synthesized silver nanoparticles, *BioNanoScience*, 2021, vol. 11, pp. 489–496. https://doi.org/10.1007/s12668-021-00824-7
22. Abdal Dayem, A., Hossain, M.K., Lee, S.B., et al., The role of reactive oxygen species (ROS) in the biological activities of metallic nanoparticles, *Int. J. Mol. Sci.*, 2017, vol. 18, no. 1, p. 120. https://doi.org/10.3390/ijms18010120
23. Maheshwari, K., Agrawal, M., and Gupta, A.B., Dye pollution in water and wastewater, in *Novel Materials for Dye-Containing Wastewater Treatment. Sustainable Textiles: Production, Processing, Manufacturing and Chemistry*, Singapore: Springer, 2021, pp. 1–25. https://doi.org/10.1007/978-981-16-2892-4_1
24. Al-Tohamy, R., Ali, S.S., Li, F., et al., A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety, *Ecotoxicol. Environ. Saf.*, 2022, vol. 231, p. 113160. https://doi.org/10.1016/j.ecoenv.2021.113160
25. Yusuf, M., Synthetic dyes: A threat to the environment and water ecosystem, in *Textiles and Clothing. Chapter 2*, Wiley, 2019, pp. 11–26. https://doi.org/10.1002/9781119526599.ch2
26. Rathinam, R., Brindha, T., Dheenadhayalan, S., et al., Removal of colours in textile wastewater by electrochemical methods: A review, *Asian J. Chem.*, 2023, vol. 35, no. 6, pp. 1291–1295. https://doi.org/10.14233/ajchem.2023.27472
27. Dutta, S., Adhikary, S., Bhattacharya, S., et al., Contamination of textile dyes in aquatic environment: Adverse impacts on aquatic ecosystem and human health, and its management using bioremediation. *J. Environ. Manage.*, 2024, vol. 353, p. 120103. https://doi.org/10.1016/j.jenvman.2024.120103
28. Islam, T., Repon, M.R., Islam, T., et al., Impact of textile dyes on health and ecosystem: A review of structure, causes, and potential solutions, *Environ. Sci. Pollut. Res.*, 2023, vol. 30, pp. 9207–9242. https://doi.org/10.1007/s11356-022-24398-3
29. Srivastava, A., Rani, R.M., Patle, D.S., et al., Emerging bioremediation technologies for the treatment of textile wastewater containing synthetic dyes: A comprehensive review, *J. Chem. Technol. Biotechnol.*, 2022, vol. 97, no. 1, pp. 26–41. https://doi.org/10.1002/jctb.6891
30. Roy, A., Sharma, A., Yadav, S., et al., Nanomaterials for remediation of environmental pollutants, *Bioinorg. Chem. Appl.*, 2021, vol. 2021, p. 1764647. https://doi.org/10.1155/2021/1764647
31. Dheyab, M. A., Oladzadabbasabadi, N., Aziz, A. A., et al., Recent advances of plant-mediated metal nanoparticles: Synthesis, properties, and emerging applications for wastewater treatment, *J. Environ. Chem. Eng.*, 2024, vol. 12, no. 2, p. 112345. https://doi.org/10.1016/j.jece.2024.112345
32. Bhatt, P., Pandey, S.C., Joshi, S., et al., Nanobioremediation: A sustainable approach for the removal of toxic pollutants from the environment, *J. Hazard. Mater.*, 2022, vol. 427, p. 128033. https://doi.org/10.1016/j.jhazmat.2021.128033
33. Sur, U.K., Ankamwar, B., Karmakar, S., et al., Green synthesis of silver nanoparticles using the plant extract of Shikakai and Reetha, *Mater. Today: Proc.*, 2018, vol. 5, no. 1, pp. 2321–2329. https://doi.org/10.1016/j.matpr.2017.09.236
34. Zhang, X.F., Liu, Z.G., Shen, W., et al., Silver nanoparticles: Synthesis, characterization, properties, applications, and therapeutic approaches, *Int. J. Mol. Sci.*, 2016, vol. 17, no. 9, p. 1534. https://doi.org/10.3390/ijms17091534
35. Gautam, D., Lal, S., and Hooda, S., Adsorption of rhodamine 6G dye on binary system of nanoarchitectonics composite magnetic graphene oxide material, *J. Nanosci. Nanotechnol.*, 2020, vol. 20, no. 5, pp. 2939–2945. https://doi.org/10.1166/jnn.2020.17442
36. Saya, L., Gautam, D., Malik, V., et al., Natural polysaccharide based graphene oxide nanocomposites for removal of dyes from wastewater: A review, *J. Chem. Eng. Data*, 2020, vol. 66, no. 1, pp. 11–37. https://doi.org/10.1021/acs.jced.0c00743
37. Cos, P., Ying, L., Calomme, M., et al., Structure-activity relationship and classification of flavonoids as inhibitors of xanthine oxidase and superoxide scavengers, *J. Nat. Prod.*, 1998, vol. 61, no. 1, pp. 71–76. https://doi.org/10.1021/np970237h
38. Torey, A., Sasidharan, S., Latha, L.Y., et al., Antioxidant activity and total phenolic content of methanol extracts of *Ixora coccinea, Pharm. Biol.*, 2010, vol. 48, no. 10, pp. 1119–1123. https://doi.org/10.3109/13880200903490505
39. Alamier, W. M., Oteef, M.D.Y., Bakry, A.M., et al., Green synthesis of silver nanoparticles using *Acacia ehrenbergiana* plant cortex extract for efficient removal of rhodamine B cationic dye from wastewater and the evaluation of ant imicrobial activity, *ACS Omega*, 2023, vol. 8, no. 21, pp. 18901–18914. https://doi.org/10.1021/acsomega.3c01292
40. Malik, V., Saya, L., Gautam, D., et al., Review on adsorptive removal of metal ions and dyes from wastewater using tamarind-based biocomposites, *Polym. Bull.*, 2022, vol. 79, pp. 9267–9302. https://doi.org/10.1007/s00289-021-03991-5
41. Scimeca, M., Bischetti, S., Lamsira, H.K., et al., Energy Dispersive X-ray (EDX) microanalysis: A powerful tool in biomedical research and diagnosis, *Eur. J. Histochem.*, 2018, vol. 62, no. 1, p. 2841. https://doi.org/10.4081/ejh.2018.2841
42. Saiyed, T.I., Biosynthesis of silver nanoparticles using plant extracts and their application in water treatment, *Doctoral Dissertation*, North-West University, South Africa, 2018.
43. Nestor, S.M., Rupsingh, R., Borrie, M., et al., Ventricular enlargement as a possible measure of Alzheimer's disease progression validated using the Alzhei-

mer's disease neuroimaging initiative database, *Brain*, 2008, vol. 131, no. 9, pp. 2443–2454. https://doi.org/10.1093/brain/awn146

44. Mehta, B.K., Chhajlani, M., and Shrivastava, B.D., Green synthesis of silver nanoparticles and their characterization by XRD, *J. Phys.: Conf. Ser.*, 2017, vol. 836, p. 012050. https://doi.org/10.1088/1742-6596/836/1/012050

45. Gautam, D. and Hooda, S., Magnetic graphene oxide/chitin nanocomposites for efficient adsorption of methylene blue and crystal violet from aqueous solutions, *J. Chem. Eng. Data*, 2020, vol. 65, no. 8, pp. 4052–4062. https://doi.org/10.1021/acs.jced.0c00350

46. Ji, X., Kan, G., Jiang, X., et al., A monodisperse anionic silver nanoparticles colloid: Its selective adsorption and excellent plasmon-induced photodegradation of Methylene Blue, *J. Colloid Interface Sci.*, 2018, vol. 523, pp. 98–109. https://doi.org/10.1016/j.jcis.2018.03.011

47. Garcia-Segura, S., El-Ghenymy, A., Centellas, F., et al., Comparative degradation of the diazo dye direct yellow 4 by electro-Fenton, photoelectro-Fenton and photo-assisted electro-Fenton, *J. Electroanal. Chem.*, 2012, vol. 681, pp. 36–43. https://doi.org/10.1016/j.jelechem.2012.06.002

48. Nagargoje, R., Atalay, S., Ersoz, G. A., et al., Photo-Fenton oxidation of azo dyes in textile wastewaters in the presence of FE/AC and FE-TIO_2/AC catalysts, *Bombay Technol.*, 2014, vol. 64, no. 1, pp. 41–53.

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Enhancing Thermo-Mechanical Properties of Epoxy Nanocomposites with Dispersed MWCNTs Using a Novel Hybrid Mixing Technique

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Abstract

This study presents an innovative approach to enhance the thermo-mechanical properties of multi-walled carbon nanotube (MWCNT) reinforced epoxy nanocomposites through a dual-action dispersion method. By simultaneously applying ultrasonic energy and shear force via an axial-flow impeller, a uniform distribution of MWCNTs within the epoxy matrix was achieved without the need for chemical modification. The impact of MWCNT loading (0.25 - 1.0 wt%) on the thermal and mechanical behavior of the composites was systematically investigated. Dynamic mechanical analysis revealed a significant improvement in storage modulus, with a maximum enhancement observed at 0.75 wt% MWCNT content. Thermogravimetric analysis demonstrated increased thermal stability, confirming the efficiency of nanotube reinforcement. Scanning electron microscopy of fracture surfaces validated the homogeneity of nanotube distribution and provided insights into fracture mechanics. These findings suggest that the adopted hybrid dispersion technique is effective for fabricating high-performance polymer nanocomposites for structural applications.

Keywords

MWCNTs, Epoxy Resin and Nanocomposites

1. Introduction

Carbon nanotubes (CNTs), particularly multi-walled carbon nanotubes (MWCNTs), have garnered extensive attention since their discovery by Iijima in 1991 due to their extraordinary mechanical strength, electrical conductivity, and thermal stability [1]. These characteristics make MWCNTs exceptional candidates for reinforcing polymers, ceramics, and metals across a wide range of applications, including aerospace, automotive, and electronics [2] [3].

In polymer nanocomposites, the integration of MWCNTs has been shown to significantly improve mechanical stiffness, toughness, and thermal performance [4]-[6]. However, the full potential of MWCNTs can only be realized if they are uniformly distributed and strongly bonded within the polymer matrix. Aggregation of nanotubes—caused by van der Waals forces and high surface energy—often results in inhomogeneous composites with reduced or inconsistent performance [7] [8].

To address the issue of dispersion, researchers have explored various strategies, such as mechanical stirring, ultrasonication, melt blending, and chemical functionalization of the nanotube surfaces [9]-[11]. While chemical functionalization can improve dispersibility and interfacial bonding, it may also compromise the intrinsic structure and properties of CNTs [12]. Thus, physical dispersion methods remain a desirable alternative for preserving nanotube integrity while achieving effective distribution. Previous studies have shown that combining ultrasonication with shear mixing can significantly improve dispersion quality [13] [14]. For instance, Thostenson *et al.* demonstrated the effectiveness of high shear extrusion in dispersing CNTs in thermoplastics [15], while Guadagno *et al.* reported improvements in epoxy composites using ultrasonication [16]. Nevertheless, there remains a need for scalable, efficient techniques that ensure both uniform dispersion and enhanced interaction with the matrix.

The enhanced thermo-mechanical properties achieved through uniform dispersion of MWCNTs make these nanocomposites promising candidates for structural and functional components in high-performance applications. Specifically, they can be applied in aerospace parts where weight-to-strength ratio is critical, automotive components requiring impact resistance and durability, and electronic encapsulations where thermal stability and conductivity are vital. Such applications justify the need to optimize dispersion techniques to achieve superior mechanical and thermal performance in the final composite. In this work, we propose a novel hybrid dispersion technique that simultaneously employs ultrasonic waves and mechanical shear force using an axial-flow impeller. This synergistic approach aims to de-agglomerate MWCNTs effectively and distribute them uniformly throughout an epoxy resin. The focus of this study is to investigate how this improved dispersion influences the thermo-mechanical properties of the resulting nanocomposites, including storage modulus, glass transition temperature, and thermal stability.

2. Experimental Procedure

2.1. Materials

The primary components for composite fabrication included multi-walled carbon nanotubes (MWCNTs) produced via chemical vapor deposition (CVD), with an average diameter of approximately 30 nm and the length of MWCNTs is fall in the range of 20 to 45 μm. The cobalt oxide nano particles on alumina substrate are used as catalyst in growth of MWCNTs. The polymer matrix was an epoxy resin (Camcoat-2071 Bisphenol A based) paired with a compatible aliphatic hardener (HY-951 amine based), both sourced from Champion Advanced Materials Pvt. Ltd., India.

2.2. Composite Fabrication Procedure

A predetermined amount of MWCNTs (ranging from 0.25 to 1.0 wt%) was first dispersed into the epoxy resin with the aid of 10% acetone to temporarily reduce viscosity and assist in preliminary mixing. This mixture underwent manual stirring with a glass rod to pre-disperse the nanotubes.

Subsequently, a hybrid dispersion process was employed. The MWCNT-epoxy-acetone mixture was treated using a dual-action technique: ultrasonic energy was applied using a titanium alloy (Ti-6Al-4V) probe (13 mm diameter) operating at 20 kHz and 750 W, while simultaneously agitating the mixture using an axial-flow impeller (Mixture volume-50 ml, Impeller blade angle-45˚, Diameter of impeller-2.5 cm). The probe was positioned outside the primary vortex zone to enhance cavitation and disrupt MWCNT clusters through repeated sonic pulses. The impeller, rotating at 400 rpm, ensured effective flow dynamics and shear force throughout the 50 mL batch. The sonication amplitude was set at 60% with intermittent pulsing (10 s on/10 s off) for a duration of 30 minutes. To maintain thermal stability during dispersion, the beaker was externally cooled, limiting the temperature rise to 45 ˚C.

After processing, the acetone was allowed to evaporate completely. The hardener (10 wt% of total epoxy weight) was then thoroughly blended into the MWCNT-epoxy mixture. The resultant formulation was degassed under vacuum to eliminate entrapped air bubbles and poured into silicone rubber molds to shape the samples. Curing was performed in a hot air oven at 50˚C for 12 hours.

2.3. Dynamic Mechanical Analysis (DMA)

Thermo-mechanical behavior was analyzed using a PerkinElmer DMA 8000 system configured in single cantilever bending mode. Tests were conducted in the temperature range of 35˚C to 160˚C, with a controlled heating rate of 2˚C/min and a constant frequency of 1 Hz, following ASTM D4065 guidelines. The sample dimensions were approximately 9.2 mm × 7.5 mm × 2.5 mm.

2.4. Thermogravimetric Analysis (TGA)

Thermal stability was assessed using a STA-204 F1 instrument from Netzsch. Ran-

dom fragments from cured composite samples were heated from room temperature to 550˚C at a rate of 10˚C/min under nitrogen flow. Alumina served as the reference material.

2.5. Morphological Characterization

To evaluate the dispersion of MWCNTs and the fracture surface features, field emission scanning electron microscopy (FESEM) was performed on gold-coated tensile fracture samples. An accelerating voltage of 15 kV was applied during imaging.

3. Results and Discussion

3.1. Thermo-Mechanical Behavior

The dynamic mechanical performance of the MWCNT-reinforced epoxy composites was evaluated to determine the influence of nanotube content and dispersion quality on stiffness and thermal transitions. As shown in Figure 1, the storage modulus (E') of the nanocomposites exhibited a noticeable increase with increasing MWCNT content up to 0.75 wt%, beyond which the modulus slightly declined. At 35˚C, a 0.75 wt% loading led to an approximately 35% improvement in modulus compared to the neat epoxy, suggesting efficient stress transfer through a well-dispersed nanotube network.

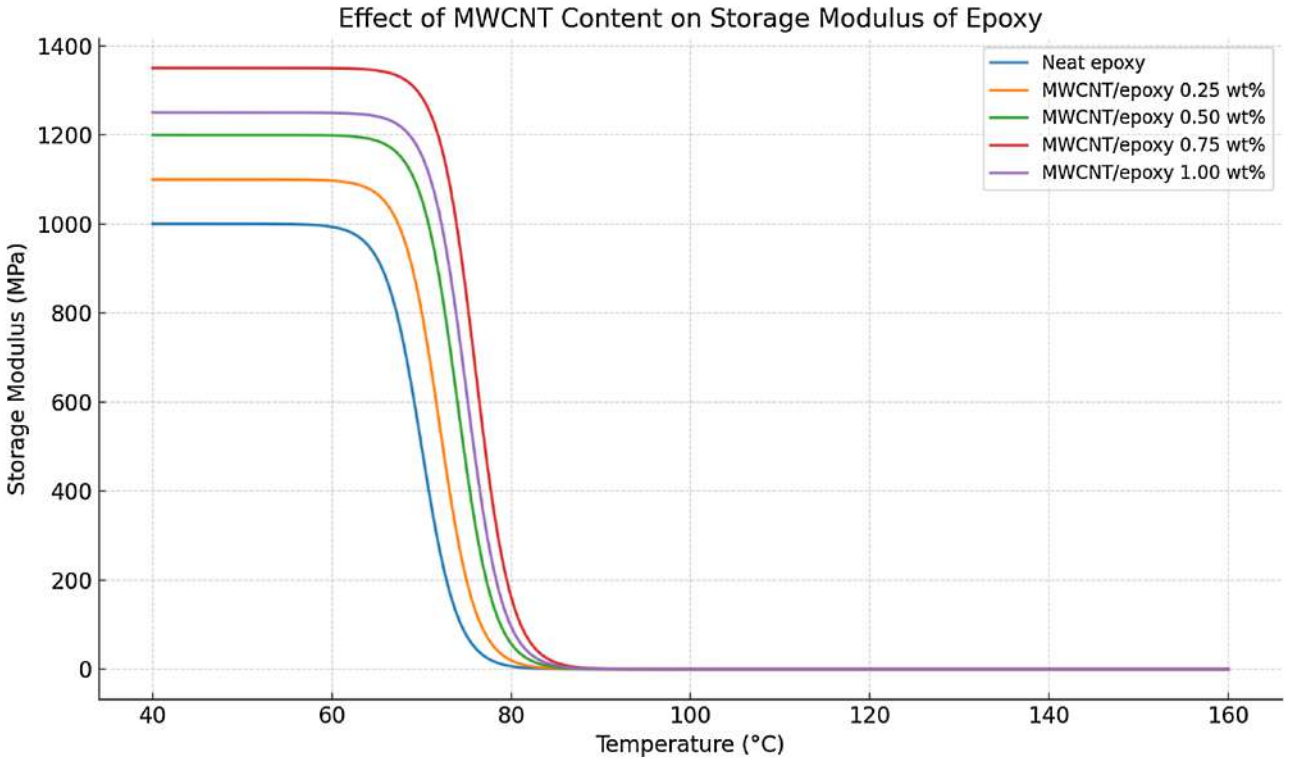

Figure 1. Storage modulus (E′) as a function of temperature for neat epoxy and MWCNT/epoxy nanocomposites. A significant increase in modulus is observed up to 0.75 wt% MWCNT loading, indicating improved stiffness due to enhanced dispersion and interaction.

The reduction in modulus at 1.0 wt% MWCNT may be attributed to the onset of nanotube aggregation, which disrupts the continuous polymer network and diminishes reinforcement efficiency. Similar non-linear trends in modulus with increasing filler content have been reported in earlier studies [17] [18].

The glass transition temperature (Tg), as determined from the peak of the tan δ curves (**Figure 2**), also shifted to higher values with increasing nanotube content. Neat epoxy showed a Tg of approximately 78 ˚C, which rose to nearly 88˚C for the 0.75 wt% MWCNT composite. This increase is indicative of restricted segmental mobility in the polymer chains due to strong interfacial interactions with dispersed MWCNTs [19]-[24]. The drop in Tg at 1.0 wt% reinforces the hypothesis of poor dispersion and weaker interfacial adhesion at higher loadings.

Furthermore, the tan δ peak height decreased with MWCNT addition, pointing to increased material stiffness and energy dissipation capacity—features favorable for applications involving vibration damping [20] [23].

To assess the degree of interfacial bonding quantitatively, an interaction parameter (B) was calculated using the equation proposed by Ziegel and Romanov [21]. The highest B value corresponded to the 0.75 wt% sample, confirming optimal filler-matrix compatibility at this concentration.

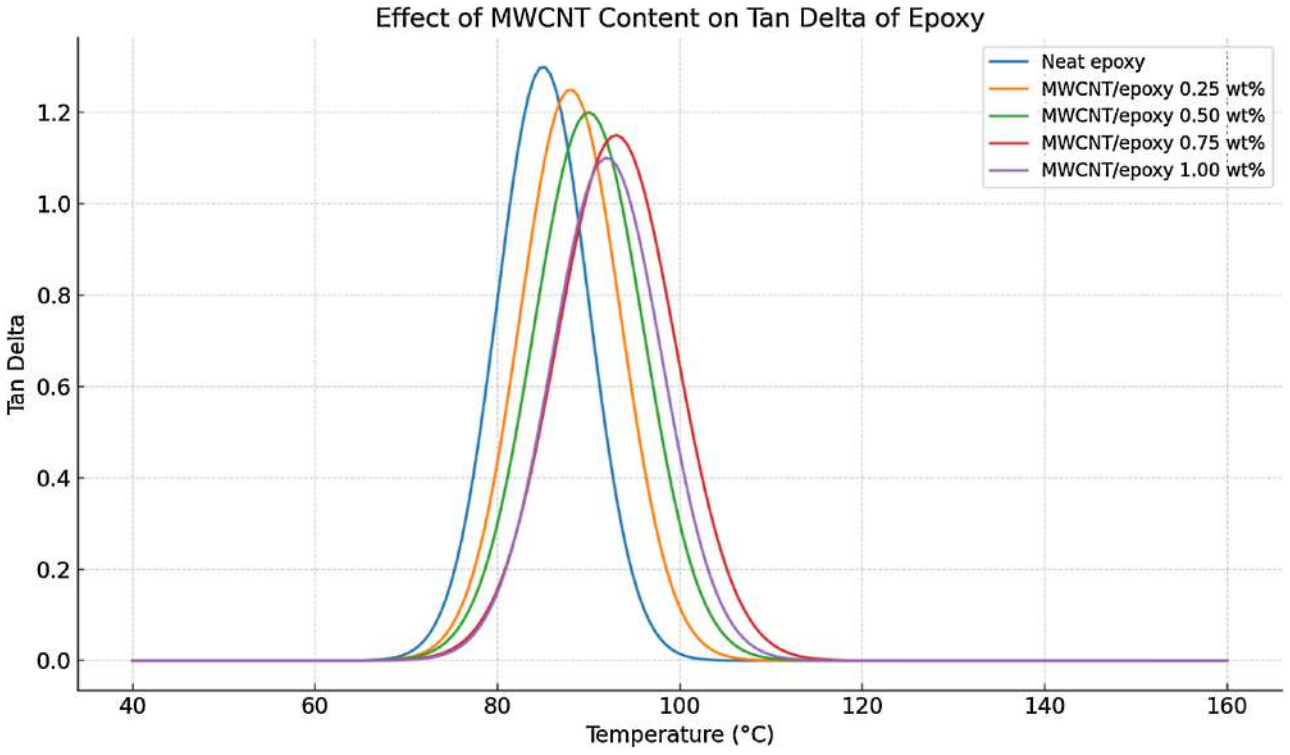

Figure 2. Variation of tan δ with temperature for different MWCNT loadings in epoxy matrix. The peak shift towards higher temperatures and the reduction in peak height signify increased glass transition temperature and material stiffness with MWCNT reinforcement.

3.2. Thermal Stability

The thermal stability of the composites was examined via thermogravimetric anal-

ysis. As illustrated in Figure 3, the onset of degradation, defined at 5% and 10% weight loss, shifted to higher temperatures as the MWCNT content increased. For example, at 0.75 wt% loading, the degradation temperature rose by nearly 15˚C compared to neat epoxy.

This improvement is ascribed to the barrier effect of MWCNTs, which inhibit the escape of volatile degradation products and delay thermal decomposition [25]. Moreover, the nanotubes may act as radical scavengers, suppressing the propagation of degradation reactions [24] [26]. The thermal behavior observed in this study aligns well with prior findings on carbon nanomaterial-reinforced polymers [27].

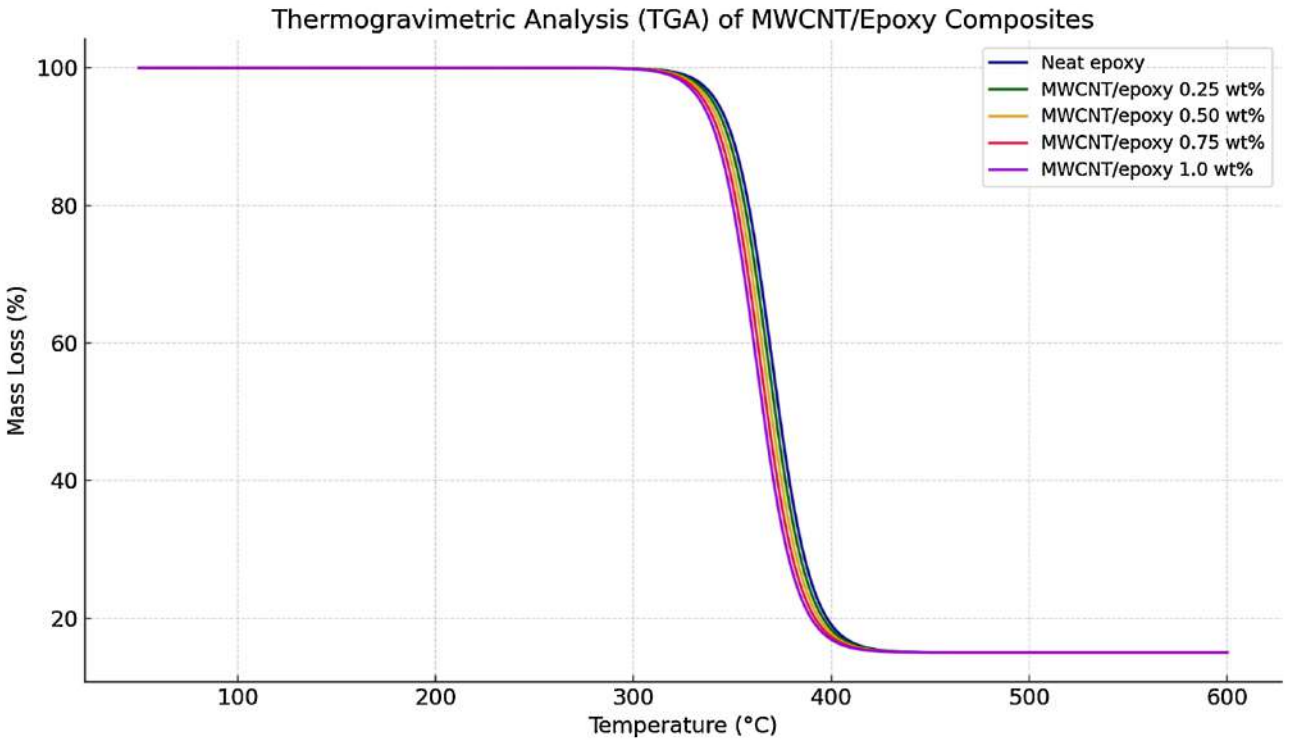

Figure 3. Thermogravimetric analysis (TGA) curves for neat epoxy and MWCNT/epoxy composites. The degradation temperatures increase with MWCNT addition up to 0.75 wt%, indicating enhanced thermal stability.

3.3. Fracture Surface Morphology

Field emission scanning electron microscopy (FESEM) images of the fracture surfaces (Figure 4) further confirmed the effect of dispersion on composite behavior. Neat epoxy exhibited smooth, river-like fracture patterns, characteristic of brittle failure. In contrast, the composites displayed rougher, more tortuous surfaces indicative of enhanced energy dissipation during fracture.

At 0.75 wt% MWCNTs, the fracture surface was densely populated with pulled-out nanotubes and deflected crack paths, implying strong matrix-filler interaction. At 1.0 wt%, however, visible clusters of MWCNTs were detected, acting as flaws that weaken the composite, consistent with the observed drop in mechanical performance.

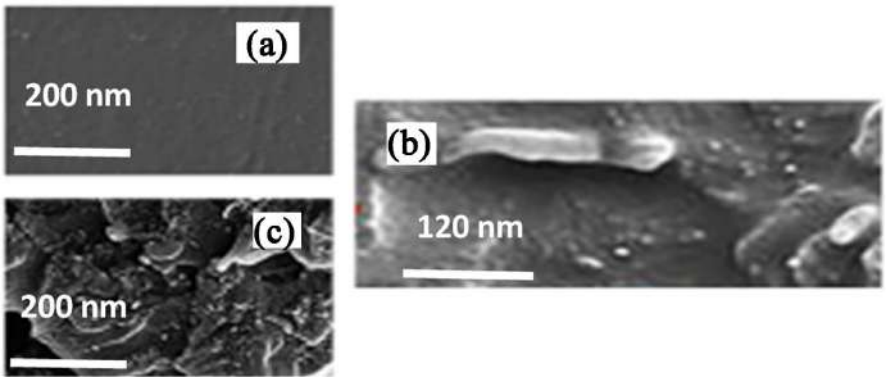

Figure 4. FESEM images of fracture surfaces: (a) neat epoxy, showing smooth and brittle fracture surface; (b) 0.75 wt%, displaying dense nanotube dispersion and rough fracture; (c) 1.00 wt%, where clustering of MWCNTs begins to appear, indicating reduced dispersion quality.

Such morphological features corroborate the mechanical and thermal trends and are in agreement with literature reporting that uniform nanotube dispersion contributes to increased fracture resistance [28] [29].

4. Conclusions

In this study, a dual-action dispersion technique employing ultrasonic waves and axial-flow shear mixing was successfully utilized to achieve homogeneous distribution of multi-walled carbon nanotubes (MWCNTs) within an epoxy matrix. The integration of this novel hybrid method demonstrated clear improvements in the thermo-mechanical performance of the resulting nanocomposites.

Dynamic mechanical analysis revealed that the storage modulus and glass transition temperature increased notably with MWCNT loading, peaking at 0.75 wt%, indicating enhanced stiffness and restricted molecular mobility due to strong interfacial bonding. Thermal stability, as assessed by TGA, also improved with increasing MWCNT content up to 0.75 wt%, owing to the barrier and radical-scavenging effects of well-dispersed nanotubes.

However, exceeding the 0.75 wt% threshold led to diminishing returns or slight reductions in all measured properties, attributed to the formation of MWCNT clusters that act as defects within the polymer matrix. FESEM observations of fracture surfaces corroborated these findings by visually confirming the transition from uniform dispersion to visible aggregation at higher nanotube loadings.

Overall, the findings suggest that the hybrid dispersion method is a highly effective, scalable approach for enhancing the mechanical and thermal characteristics of epoxy nanocomposites. The optimal MWCNT loading identified in this work (0.75 wt%) provides a benchmark for developing high-performance structural materials in aerospace, automotive, and advanced engineering applications.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Iijima, S. (1991) Helical Microtubules of Graphitic Carbon. *Nature*, **354**, 56-58. https://doi.org/10.1038/354056a0

[2] Baughman, R.H., Zakhidov, A.A. and de Heer, W.A. (2002) Carbon Nanotubes—The Route toward Applications. *Science*, **297**, 787-792. https://doi.org/10.1126/science.1060928

[3] Zheng, H., Zhang, W., Li, B., Zhu, J., Wang, C., Song, G., *et al.* (2022) Recent Advances of Interphases in Carbon Fiber-Reinforced Polymer Composites: A Review. *Composites Part B: Engineering*, **233**, Article ID: 109639. https://doi.org/10.1016/j.compositesb.2022.109639

[4] Spitalsky, Z., Tasis, D., Papagelis, K. and Galiotis, C. (2010) Carbon Nanotube-Polymer Composites: Chemistry, Processing, Mechanical and Electrical Properties. *Progress in Polymer Science*, **35**, 357-401. https://doi.org/10.1016/j.progpolymsci.2009.09.003

[5] Mohd Nurazzi, N., Asyraf, M.R.M., Khalina, A., Abdullah, N., Sabaruddin, F.A., Kamarudin, S.H., *et al.* (2021) Fabrication, Functionalization, and Application of Carbon Nanotube-Reinforced Polymer Composite: An Overview. *Polymers*, **13**, Article 1047. https://doi.org/10.3390/polym13071047

[6] Wang, Y., Tang, B., Gao, Y., Wu, X., Chen, J., Shan, L., *et al.* (2021) Epoxy Composites with High Thermal Conductivity by Constructing Three-Dimensional Carbon Fiber/Carbon/Nickel Networks Using an Electroplating Method. *ACS Omega*, **6**, 19238-19251. https://doi.org/10.1021/acsomega.1c02694

[7] Ogbonna, V.E., Popoola, A.P.I. and Popoola, O.M. (2022) A Review on Recent Advances on the Mechanical and Conductivity Properties of Epoxy Nanocomposites for Industrial Applications. *Polymer Bulletin*, **80**, 3449-3487. https://doi.org/10.1007/s00289-022-04249-4

[8] Peigney, A., Laurent, C., Flahaut, E., Bacsa, R.R. and Rousset, A. (2001) Specific Surface Area of Carbon Nanotubes and Bundles of Carbon Nanotubes. *Carbon*, **39**, 507-514. https://doi.org/10.1016/s0008-6223(00)00155-x

[9] Pegel, S., Pötschke, P., Petzold, G., Alig, I., Dudkin, S.M. and Lellinger, D. (2008) Dispersion, Agglomeration, and Network Formation of Multiwalled Carbon Nanotubes in Polycarbonate Melts. *Polymer*, **49**, 974-984. https://doi.org/10.1016/j.polymer.2007.12.024

[10] Kim, M.T., Rhee, K.Y., Park, S.J. and Hui, D. (2012) Effects of Silane-Modified Carbon Nanotubes on Flexural and Fracture Behaviors of Carbon Nanotube-Modified Epoxy/Basalt Composites. *Composites Part B: Engineering*, **43**, 2298-2302. https://doi.org/10.1016/j.compositesb.2011.12.007

[11] Abdalla, M., Dean, D., Adibempe, D., Nyairo, E., Robinson, P. and Thompson, G. (2007) The Effect of Interfacial Chemistry on Molecular Mobility and Morphology of Multiwalled Carbon Nanotubes Epoxy Nanocomposite. *Polymer*, **48**, 5662-5670. https://doi.org/10.1016/j.polymer.2007.06.073

[12] Albert, A.A., Parthasarathy, V. and Kumar, P.S. (2023) Review on Recent Progress in Epoxy-Based Composite Materials for electromagnetic Interference(EMI) Shielding Applications. *Polymer Composites*, **45**, 1956-1984. https://doi.org/10.1002/pc.27928

[13] Lachman, N. and Daniel Wagner, H. (2010) Correlation between Interfacial Molecular Structure and Mechanics in CNT/Epoxy Nano-Composites. *Composites Part A: Applied Science and Manufacturing*, **41**, 1093-1098. https://doi.org/10.1016/j.compositesa.2009.08.023

[14] Schulz, S.C., Faiella, G., Buschhorn, S.T., Prado, L.A.S.A., Giordano, M., Schulte, K., *et al.* (2011) Combined Electrical and Rheological Properties of Shear Induced Multiwall Carbon Nanotube Agglomerates in Epoxy Suspensions. *European Polymer Journal*, **47**, 2069-2077. https://doi.org/10.1016/j.eurpolymj.2011.07.022

[15] Thostenson, E.T. and Chou, T. (2002) Aligned Multi-Walled Carbon Nanotube-Reinforced Composites: Processing and Mechanical Characterization. *Journal of Physics D*: *Applied Physics*, **35**, L77-L80. https://doi.org/10.1088/0022-3727/35/16/103

[16] Guadagno, L., Naddeo, C., Vittoria, V., Sorrentino, A., Vertuccio, L., Raimondo, M., *et al.* (2010) Cure Behavior and Physical Properties of Epoxy Resin—Filled with Multiwalled Carbon Nanotubes. *Journal of Nanoscience and Nanotechnology*, **10**, 2686-2693. https://doi.org/10.1166/jnn.2010.1417

[17] Abdalla, M., Dean, D., Adibempe, D. and Nyairo, E. (2007) Interfacial Chemistry Effects on Morphology and Dynamics in MWCNT/Epoxy Nanocomposites. *Polymer*, **48**, 5662-5672.

[18] Guadagno, L., Vertuccio, L., Sorrentino, A., Raimondo, M., Naddeo, C., Vittoria, V., *et al.* (2009) Mechanical and Barrier Properties of Epoxy Resin Filled with Multi-Walled Carbon Nanotubes. *Carbon*, **47**, 2419-2430. https://doi.org/10.1016/j.carbon.2009.04.035

[19] Gojny, F.H. and Schulte, K. (2004) Functionalisation Effect on the Thermo-Mechanical Behaviour of Multi-Wall Carbon Nanotube/Epoxy-Composites. *Composites Science and Technology*, **64**, 2303-2308. https://doi.org/10.1016/j.compscitech.2004.01.024

[20] Jagtap, S., Rao, V.S. and Ratna, D. (2012) Preparation of Flexible Epoxy/Clay Nanocomposites: Effect of Preparation Method, Clay Modifier and Matrix Ductility. *Journal of Reinforced Plastics and Composites*, **32**, 183-196. https://doi.org/10.1177/0731684412462916

[21] Ziegel, K.D. and Romanov, A. (1973) Modulus Reinforcement in Elastomer Composites. I. Inorganic Fillers. *Journal of Applied Polymer Science*, **17**, 1119-1131. https://doi.org/10.1002/app.1973.070170410

[22] Rafiee, M.A., Rafiee, J., Wang, Z., Song, H., Yu, Z. and Koratkar, N. (2009) Enhanced Mechanical Properties of Nanocomposites at Low Graphene Content. *ACS Nano*, **3**, 3884-3890. https://doi.org/10.1021/nn9010472

[23] Curtin, W.A. and Sheldon, B.W. (2004) CNT-Reinforced Ceramics and Metals. *Materials Today*, **7**, 44-49. https://doi.org/10.1016/s1369-7021(04)00508-5

[24] Suarez, A.J., Urena, A. and Campo, M. (2013) Dispersion Techniques and Mechanical Behavior in MWCNT/Epoxy Composites. *Composites Part B*, **48**, 88-94.

[25] Harb, S.V., Pulcinelli, S.H. and Santilli, C.V. (2016) Reinforcement of Polymer Nanocomposites with Carbon Nanomaterials: Thermal Perspectives. *AACS Applied Materials & Interfaces Journal*, **8**, 16339-16350.

[26] Kumar, K., Ghosh, P.K. and Kumar, A. (2016) Enhancing Thermal and Mechanical Performance of TiO_2-Epoxy Nanocomposites. *Composites Part B*: *Engineering*, **97**, 353-360.

[27] Vertuccio, L., Guadagno, L., Spinelli, G., Lamberti, P. and Tucci, V. (2016) Nanotube-Modified Epoxy Composites for Structural Applications: Review of Thermal Effects. *Composites Part B*: *Engineering*, **107**, 192-202.

[28] Bortz, D.R., Heras, E.G. and Martin-Gullon, I. (2011) Impressive Fatigue Life and Fracture Toughness Improvements in Graphene Oxide/Epoxy Composites. *Macromolecules*, **45**, 238-245. https://doi.org/10.1021/ma201563k

[29] Kim, M.T., Rhee, K.Y., Lee, J.H., Hui, D. and Lau, A.K.T. (2011) Property Enhancement of a Carbon Fiber/Epoxy Composite by Using Carbon Nanotubes. *Composites Part B*: *Engineering*, **42**, 1257-1261. https://doi.org/10.1016/j.compositesb.2011.02.005

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Control of failure of lap shear epoxy adhesive joint through CNTs

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ABSTRACT

In this research investigation, we explore the attributes of lap shear connections, employing epoxy adhesive and a carbon nanotube-epoxy nanocomposite on a mild steel substrate. We offer an intricate portrayal of a variety of factors, encompassing the surface characteristics of mild steel, the width of the adhesive bonding layer (thickness), the affinity in term of wettability between epoxy resin as adhesive and mild steel substrate surface, and the impact of carbon nanotube (CNT) incorporation within the epoxy resin. These variables collectively exert a significant influence on sustainability of lap shear joints under stress. Our empirical findings underscore a noteworthy enhancement in the lap shear joint's strength, attributed to the even dispersion of CNTs within the polymer matrix, with consequent modifications in the surface of substrate. Furthermore, these alterations induce a shift in the failure mode exhibited by lap shear connections. Remarkably, the introduction of 0.5 weight percent of CNTs into the epoxy adhesive emerges as the most substantial contributor to the augmentation in lap shear strength.

KEYWORDS: **CNTs; Mild Steel; Epoxy; Adhesive; Lap shear joints.**

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1. Introduction

Epoxy constitutes a two-component system resulting from a cross-linking reaction, commonly known as curing, between epoxide groups in one component and nucleophile groups in the second component. The presence of this cross-linking network transforms epoxy into a thermosetting polymer with commendable mechanical and thermal properties.

Nonetheless, this cross-linking imparts a brittle nature to epoxy, which limits its applicability. Depending on the degree of cross-linking, epoxy can exhibit a wide range of properties, including respectable tensile performance, minimal shrinkage during curing, strong chemical resistance, high anti-corrosion properties, environmental resilience, dimensional stability, and excellent adhesion [1–7]. Epoxy finds extensive use as an adhesive in the automobile and aircraft industries, as an electrical insulating material in the electric and electronics sectors, as a coating material, and in composite materials [1-7]. Epoxy-based adhesives offer numerous advantages in comparison to other adhesives such as even stress distribution, the ability to bond different material surfaces, effective sealing, and relatively low weight compared to mechanical fastenings [8]. However, the brittle nature of epoxy limits its application, particularly in metal adhesive joints, due to lower resistance to crack propagation [9–11]. To boost the performance of epoxy, it has become common practice to incorporate various nano-fillers, resulting in epoxy nanocomposites with promising potential for bonding diverse components. These nanocomposites demonstrate improvements in key properties like increased modulus, thermal stability, toughness, and strength [12–15]. Carbon nanotubes (CNTs), among the favored nano-fillers for epoxy, are notable for their ability to improve physical, mechanical, electrical, anti-corrosion, and adhesive [16–24]. However, the literature on the impact of CNTs on epoxy-based joints remains somewhat limited. The effectiveness of a nano fillers reinforced adhesive depends on various factors, including the even dispersion of nano fillers, adherent material thickness, substrate surface topography, adhesive bond line thickness, and the adhesive's ability to wet the substrate. Historically, diverse methods such as in-situ polymerization, extrusion, ball milling, melt milling, electrospinning, surface modification of fillers, and ultrasonic mixing have been employed to achieve a uniform and agglomerate-free dispersion of nano fillers. This uniform dispersion significantly enhances the nanocomposite's performance [25–33]. Furthermore, mechanical polishing and chemical reaction on metallic substrate have been applied to improve the wettability and joint strength between the adhesive and the metallic substrate [34–37]. An appropriate surface roughness on the substrate contributes positively to adhesive performance by providing a larger surface area for mechanical interlocking between the adhesive and substrate [38]. Mechanical treatments serve a dual purpose, eliminating surface contaminants such as greases, dust, oils and oxides layers while simultaneously imparting surface roughness, leading to increased bond strength. The temperature and duration of reaction that generates cross linking network (epoxy curing of epoxy) also significantly affect the performance of joint [37, 38]. In the realm of adhesives, the width of the adhesive layer between substrate, (also called bond line thickness), emerges as a critical factor influencing joint strength, primarily due to the relatively brittle nature of neat epoxy.

However, the relationship between strength of joint and thickness remains a subject of ongoing investigation. In contrast to classical analyses, experimental observations suggest that joint performance may not necessarily improve with an increase in bond line thickness [39, 40]. Consequently, there is a pressing need for a more comprehensive understanding of how the wettability of epoxy and CNT-epoxy nanocomposites on the substrate, bond line thickness (width of joint), and different substrate surface morphologies collectively influence joint strength.

2. Experimental

2.1. Materials

Lap joints were constructed using mild steel strips, which are commercially available with a thickness of 2.2 mm. Two types of adhesives were employed in the fabrication process: neat epoxy and a CNT-epoxy nanocomposite. The CNTs utilized in this research are multi-walled carbon nanotubes (MWCNTs) (Diameter -38 nm), as illustrated in **Fig. 1.** These MWCNTs were synthesized through the chemical vapor deposition method. Additionally, the adhesive consisted of resin and an aliphatic hardener obtained from Huntsman Company, serving as the base material for the adhesive.

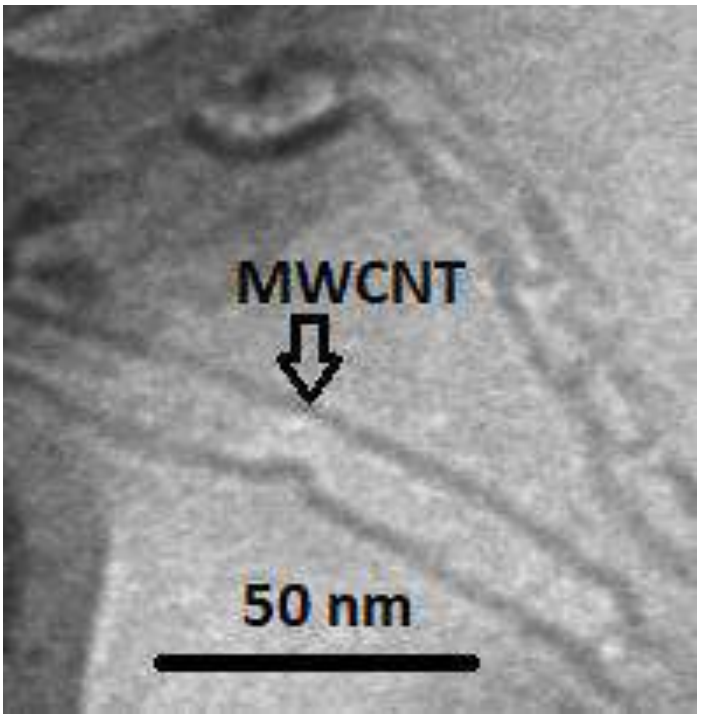


Fig.1. TEM image of multi-walled carbon nanotubes (MWCNTs).

2.2. Preparation of mild steel substrate

Surface modification of the substrate involved both mechanical polishing and chemical procedures to ensure proper preparation. To prepare the faying surface, a mechanical process was employed, involving the use of 220-grade emery paper for polishing [41]. This procedure was carried out to remove contaminants such as metal oxides, dirt, and grease. A chemical treatment procedure adhering to the ASTM D2651 standard was followed. In this process, a strip of substrate was immersed for 3 minutes in a solution (10 wt.% H_2SO_4 and 10 wt.% oxalic acid in water). Subsequently, the steel strip underwent a rinsing step with deionized (DI) H_2O for 4 minutes. To maintain surface pH at 7 (Neutralization) the, a solution containing NaOH (2 wt.%) was utilized. Following this, the surface was thoroughly rinsed with tap H_2O and then dried at a temperature of 65°C.

2.3. Characterization of substrate

The prepared surfaces of the substrate, which underwent both mechanical and chemical treatments, were examined using a Field Emission Scanning Electron Microscope (FESEM) operating at an accelerated voltage of 15 kV. Additionally, to assess the substrate surface roughness, a Mitutoyo SJ 400 profilometer was employed.

2.4. Preparation of CNT-epoxy nano-composite adhesive

Initially, an amine-based hardener was introduced into the resin (10 wt.%). The two components were meticulously mixed using a glass rod, and subsequent vacuum degassing was performed to eliminate any trapped air. The resulting adhesive, composed of neat epoxy, was then utilized to fabricate adhesive joints for mild steel, as depicted in **Fig. 2**. To formulate the CNT-epoxy nanocomposite adhesive, the following procedure was meticulously followed. Initially, CNTs (0.5 wt.%) were mixed into the resin. To reduce the mixture's viscosity, 15 wt.% of acetone was introduced, and thorough mixing of the two components was achieved using a glass rod. Ultrasonic waves were then employed, generated by a Vibracell ultrasonic processor, for a duration of 60 minutes at 70% amplitude, utilizing a pulse cycle (10 seconds on and 10 seconds off) to ensure the dispersion of CNTs, as illustrated in **Fig. 2**. Following the ultrasonic treatment, the mixture was maintained at 50°C to facilitate the vaporization of acetone. Subsequently, the hardener (10 wt.%) was evenly blended into the mixture, followed by vacuum degassing to eliminate any trapped air. The resulting CNT-epoxy nanocomposite adhesive was then employed in the creation of adhesive joints.

2.5. Fabrication of lap shear joints

Lap shear joints were meticulously fabricated on mild steel substrates utilizing two distinct types of adhesives: neat epoxy adhesive and CNT-epoxy nanocomposite adhesive (shortly called CNT-epoxy Adhesive), adhering to the procedural guidelines outlined in the ASTM D1002 standard. The adhesives were evenly spread across both surfaces of the mild steel substrate to ensure complete coverage and optimal adhesion. These prepared surfaces were then joined together following the configuration illustrated in **Fig. 3**. Throughout the assembly of adhesive joints, varying rolling loads (3 N, 6 N, 9 N, and 12 N) were applied (1.5 mm/min) to achieve different bond line thicknesses (width of joint). After the assembly, the joints were placed within an oven set at 70°C for a curing duration of 10 hours. After curing, any excess adhesive protruding beyond the joints was meticulously removed to prevent compromising the integrity of the joints. The width of joints was subsequently recorded utilizing an optical microscope.

To assess the performance of the joints under tensile stress, single lap shear testing was conducted employing a Hounsfield H25K-S machine (crosshead speed of 0.5 mm/min). The specimens of joints were securely held in position using alignment tabs, as depicted in **Fig. 3**. The lap shear strength (σ_s) of the adhesive joints, employing different adhesive types, was determined using the formula $\sigma_S = (N/X) \times Y$, (N - failure load in Newtons, X - bond line thickness in millimeters, and Y - length of joint in millimeters). The results reported here are the averages obtained from a minimum of four measurements, and a stress-strain plot was recorded until the adhesive joint reached the point of fracture.

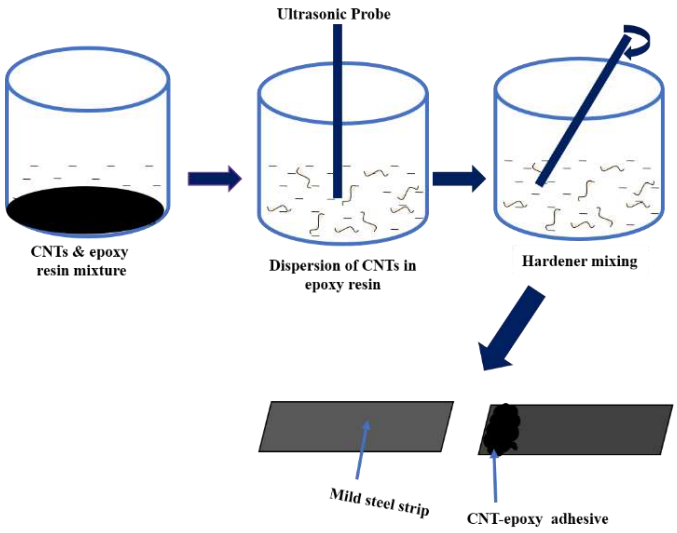


Fig. 2. Schematic diagram portrays the preparation of CNT-epoxy nanocomposite adhesive.

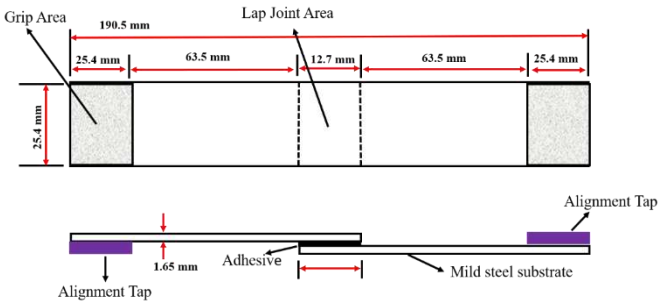


Fig. 3. Dimensions of a single lap shear adhesive joint.

3. Results and Discussion

3.1. Morphology of treated substrates

Fig. 4 displays FESEM images of the mild steel substrate, providing a comparison between surfaces prepared through mechanical polishing and chemical treatment at both low and high magnifications. In **Fig. 4(a)**, we can observe the effects of mechanical polishing, which results in parallel scratches with hills and valleys structure on substrate's surface. Conversely, **Fig. 4(b)** demonstrates the impact of chemical treatment applied on substrates after mechanically polishing, which introduces porosity through a chemical reaction within the areas corresponding to the hills and valleys.

The chemical reaction responsible for etching the mild steel substrate involves acidic action. This reaction causes positively charged Fe ions to be released into the aqueous solution from metallic Iron, leading to the creation of surface roughness in the form of porosity. This transformation is clear in **Fig. 4(b)**. The roughness measurements for both type surfaces were determined to be R_a = 0.3 mm and R_z = 2.5 mm, respectively. These measurements align with the observations derived from the FESEM images presented in **Fig. 4**.

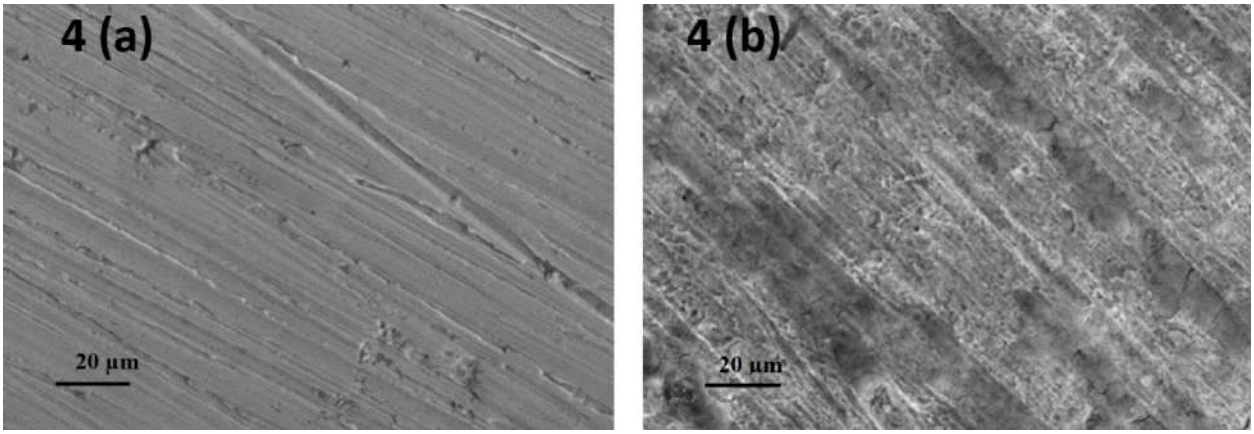


Fig. 4. FESEM images 4(a) of mechanically and 4(b) chemically treated mild steel substrates.

3.2. Wettability

The wettability of an adhesive on a substrate (Mild Steel) is a crucial factor that significantly influences the performance of a lap shear joint. In our investigation, we explored the wettability of epoxy-based adhesive towards various surfaces, including mechanically polished surface with neat epoxy, chemically modified surface with neat epoxy, and chemically modified surface with CNT-epoxy adhesive (0.5 wt.%).

To assess the wettability of these adhesives, we measured the contact angle. As depicted in **Fig. 5**, the contact angles (θ) for different adhesives on these distinct surfaces were as follows: mechanically polished surface exhibited a contact angle of 65° with neat epoxy, while chemically modified surface had a lower contact angle of 58° with neat epoxy. This indicates that chemical reaction of iron with acidic solution enhances the wettability of neat epoxy on substrate in comparison to mechanically polishing alone. However, the chemically modified surface with CNT-epoxy adhesive (0.5 wt.%) exhibited an even lower contact angle of 52°, which further affirms the enhancement in epoxy wettability attributed to the presence of CNTs.

The chemical reaction of iron with acidic solution creates a porous structure on the surface, facilitating mechanical interlocking and offering a larger adhesive area with improved surface wettability. These observations suggest that the performance of adhesive joints may be influenced by surface structure, available adhesive area, and wettability. Additionally, the presence of chemical forces between the substrate surface and the epoxy can also play an important role in deciding the performance of joints. Therefore, it is essential to investigate the lap shear strength as a function bond line thickness (width of joint). It's noteworthy that the viscosity of epoxy-based adhesive can affect its flow properties, but in our study, we observed no

significant alteration in viscosity, especially with the very low loading of CNTs (0.5 wt.%) in the epoxy-based adhesive.

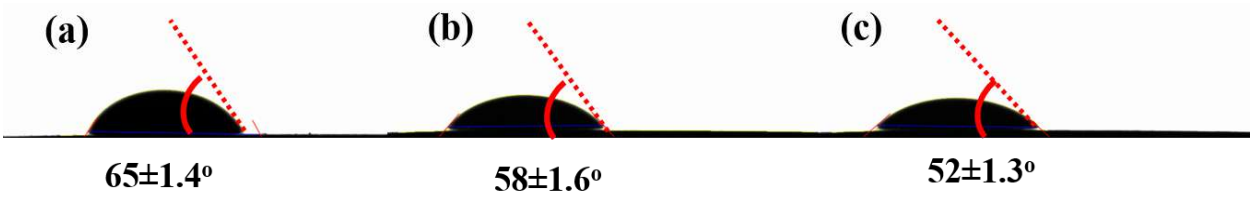


Fig. 5. Optical images of contact angles of (a) neat epoxy/mechanically polished surface, (b) neat epoxy/chemically modified surface and (c) 0.5 wt.% CNT-epoxy/chemically modified surface.

3.3. Effect of width of joint on lap shear strength for neat epoxy/mechanically polished surface

Table 1 provides valuable insights into the influence of applied rolling load during joint fabrication on the width of joints for neat epoxy applied to mechanically polished substrates (Mild steel), along with the corresponding lap shear strength. This table underscores the significant impact of the magnitude of rolling load on width of joints.

The table demonstrates that as the applied weight increases, reaching up to 9 Newtons (N), the width of joints experiences a noticeable decrease, followed by a more gradual reduction as the load continues to increase. This phenomenon suggests that at thickness (width) levels below 90 µm, the interfacial drag force exerted by the substrate surface becomes increasingly effective in securing the epoxy-based adhesive in place, thereby limiting its flow under the applied rolling load. **Fig. 6.** depicts optical micrographs of width of neat epoxy adhesive joints on mechanically polished substrate for various loads.

Table 1. Width of joints and Lap shear strength of neat epoxy adhesive for mechanically polished substrate.

Rolling load (N)	Adhesive/surface	Width of Joints (µm)	Lap shear Strength (MPa)
3	Neat epoxy/mechanically polished	152	3.1 (±0.720)
6	Neat epoxy/mechanically polished	125	4.2 (±0.837)
9	Neat epoxy/mechanically polished	90	5.9 (±0.989)
12	Neat epoxy/mechanically polished	77	3.4 (±2.126)

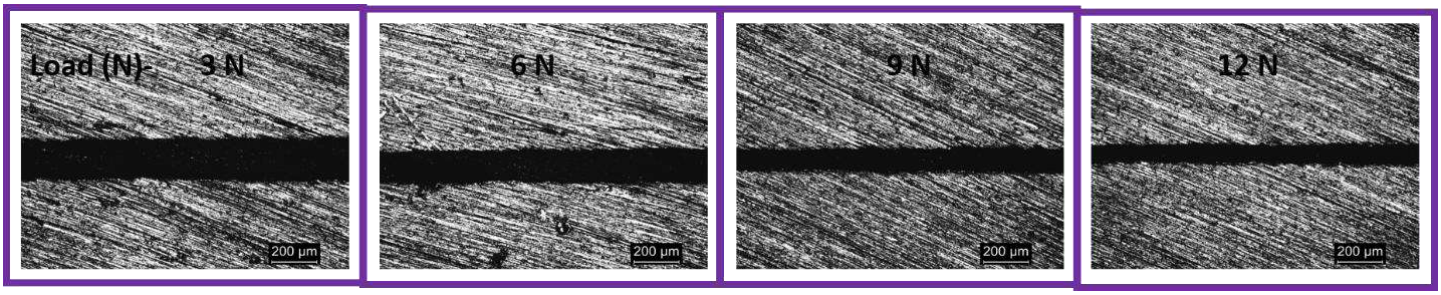


Fig. 6. Optical micrographs depicting the width of neat epoxy adhesive joints on mechanically polished substrate for various loads.

Table 1 also provides insight into how the width of neat epoxy adhesive between the substrates influences the strength of joints on mechanically polished substrates. An interesting trend is evident: as the width decreases, up to 90 µm, the laps shear strength increases. However, with a further decrease in width of joints, the strength experiences a significant decline. This reduction in lap shear strength at lower adhesive width can be attributed to the relatively higher brittleness of neat epoxy, making it susceptible to tearing due to surface tension,

which can disrupt its continuity within the adhesive joint. On the other hand, higher width of joints increases the likelihood of joint fracture by altering the triaxial stress distribution and potentially creating micro defects, such as air entrapment, within the adhesive joint. These observations underscore the intricate relationship between adhesive width between the substrate (thickness), substrate treatment, and lap shear strength, offering insights into the optimal conditions for achieving robust adhesive joints.

3.4. Shear failure modes in epoxy-based adhesive

In polymer adhesive joints, there are typically two primary modes of failure: (1) **Cohesive Failure:** In this mode, crack propagation occurs within the polymer-based adhesive itself. Cohesive failure is characterized by the presence of polymeric material on both faying surfaces of the substrate after the joint has failed. (2) **Adhesive Failure:** In this mode, crack propagation takes place along the interface between the polymer-based adhesive and substrate. Adhesive failure is characterized by one faying surface of the substrate being entirely covered by polymer, while the other faying surface lacks polymer coverage.

It's important to note that adhesive failure is typically observed in joints where neat epoxy is used with mechanically polished substrates. In such cases, only one of the faying surfaces is completely covered with neat epoxy, while the other faying surface primarily exposes the substrate surface, as confirmed in **Fig. 7.**

In contrast, for joints involving chemically modified substrates, cohesive failure is observed, as also confirmed in **Fig. 7**. Therefore, it becomes evident from **Fig. 7** results that acidic action on polished substrates wings the failure mode towards cohesive failure from adhesive failure, leading to an improvement in strength (**Table 2**). This shift can be primarily attributed to the higher wettability of neat epoxy on chemically modified substrates (**Fig. 5**) and the introduction of porosity on the surface (as shown in **Fig. 4(b)**), which facilitates mechanical interlocking and ultimately improves the lap shear strength of joints. The location of shear failure in joints is determined by the weaker of the two components: the adhesive itself and the interfacial bond between substrate and adhesive. Notably, the interfacial strength experiences significant improvement through chemical reaction applied to the metal substrate.

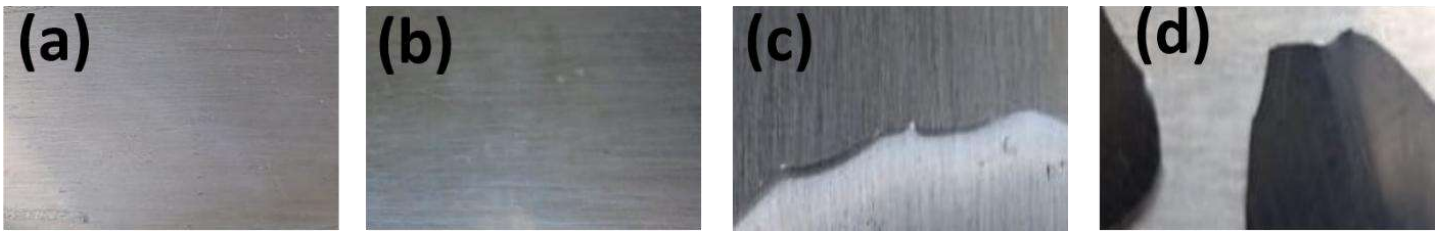


Fig. 7. Typical fracture surfaces of (a) Mechanically polished substrate without epoxy(b) Mechanically polished substrate with epoxy (c) Chemically modified substrate with epoxy (d) Chemically modified substrate with CNT-epoxy.

3.5. Lap shear strength of CNT-epoxy nanocomposite adhesives on chemically modified surface

Our current research focus revolves around enhancing the strength of epoxy-based adhesives. To accomplish this goal, we reinforced 0.5 weight percentages of carbon nanotubes into the epoxy adhesive. This nanocomposite was formed by uniformly dispersing CNTs within the cross-linking network of epoxy using ultrasonic waves, as illustrated in **Fig. 2**. Subsequently, we evaluated the strength of the resulting CNT-epoxy nanocomposites as adhesive when used on chemically modified substrates. Throughout our study, we maintained a consistent bond line thickness (width of joint) of approximately 90 µm. This specific width of joint was determined to yield the maximum strength for joints when employing neat epoxy as adhesive on mechanically polished substrates. The impact of varying CNT loading in the epoxy adhesive is visualized in **Fig. 8** and summarized in **Table 2** for chemically modified substrates. This investigation seeks to provide insights into the influence of CNT loading on the adhesive's performance under these specific conditions.

The data from **Fig. 8** and **Table 2** reveal a clear trend: as 0.50 wt.% of CNTs loaded in the epoxy adhesive, the strength of joints on chemically modified substrates experiences a noticeable improvement. The fracture behavior of CNT-epoxy adhesive joints is characterized by a mixed mode of failure, predominantly involving cohesive failure within the CNT-epoxy nanocomposite. In this mode, cracks propagate through the CNT-epoxy material, followed by interfacial fracture, as

indicated by **Fig. 7**. By examining the cohesive failure zone of neat epoxy on chemically modified substrates through FESEM image (**Fig. 9 (a)**), we observe that cracks propagate smoothly and freely, creating river-like structure. This signifies the inherent brittleness of the epoxy, which cannot effectively resist crack propagation, resulting in typical brittle fractures. The rise in strength with 0.50 wt.% CNT loading in epoxy can be attributed to the homogeneous and cluster-free dispersion of CNTs, as observed in **Fig. 9 (b)**. This dispersion results in a rougher fracture surface, with numerous circuitous pathways. A rougher surface dissipates more energy during fracture, leading to increased strength. In this case, CNTs resist cohesive fracture by deflecting crack growth through crack blunting mechanisms within the matrix. Additionally, the slightly improved wettability of CNT-epoxy on chemically modified surfaces also contributes positively to the strength enhancement of joints.

Table 2. Summarizes the strength of adhesives.

Rolling load (N)	Adhesive/surface	Width of Joints (μm)	Lap shear Strength (MPa)
9	Neat epoxy/mechanically polished	90	5.9 (±0.989)
9	Neat epoxy/chemically modified	88	7.5 (±0.798)
9	CNT-epoxy/chemically modified	88	10.2 (±1.112)

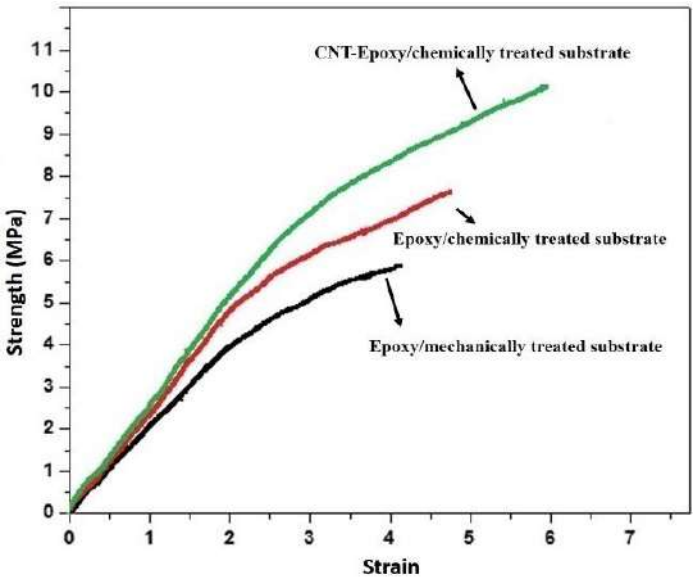
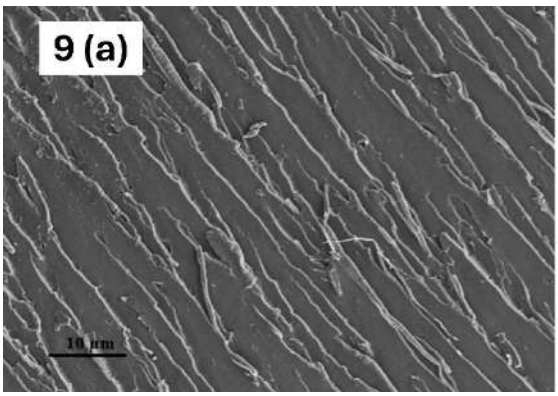


Fig. 8. Lap Shear Strength vs strain curves for various combinations of adhesive with substrate.

4. Conclusions

The strength of an adhesive is intricately tied to two critical factors: the surface characteristics of substrates and the width of joints. The application of acid treatments to metal substrate has the capacity to transform the failure mode from adhesive to cohesive failure, resulting in higher strength of joints. When CNTs are dispersed uniformly and without clustering within the polymer-based adhesive, they significantly enhance strength. This enhancement is accompanied by a mixed mode of failure observed during testing.



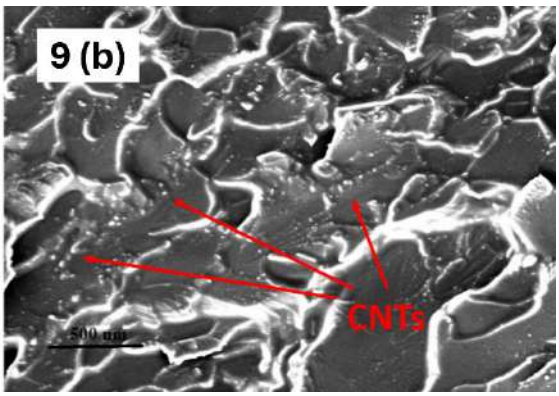


Fig. 9. Cohesive failure zone (a) Neat Epoxy (b) CNT-epoxy on chemically modified substrate (FESEM).

Disclosure statement

The authors declare no relevant financial or non-financial interests.

Data availability

Raw data of the research article is available with the authors and will be provided as per a request from the journal.

Ethical approval

Not applicable.

References

[1] A.K. Hamzat, A.Y. Adesina, T. Rasheed & M. A. Samad., Assessing the Tribological Behavior of Nanoclay-Reinforced Epoxy Coatings Under Dry Sliding and Seawater Lubricated Conditions. J. of Materi Eng and Perform., 2023, **32**, p 6905–6914. https://doi.org/10.1007/s11665-022-07605-7

[2] M. M. Liu, H. X. Hu, Z. B. Wang & Y. G. Jheng., Effect of Epoxy Sealant Loaded with Modified Montmorillonite on the Corrosion Resistance of Fe-Based Amorphous Metallic Coating. J. of Materi Eng and Perform., 2023, 32, p 7593–7610. https://doi.org/10.1007/s11665-022-07669-5

[3] Z. B. Wang, Z. Y. Wang, H. X. Hu, C. B. Liu & Y. G. Zheng., Corrosion Protection Performance of Nano-SiO_2/Epoxy Composite Coatings in Acidic Desulfurized Flue Gas Condensates. J. of Materi Eng and Perform., 2016, **25**, 3880–3889. https://doi.org/10.1007/s11665-016-2212-3

[4] R. Vasireddi & D. R. Mahapatra., Micro-crack Pinning and Interfacial Fracture in Mixed Metal Oxide Reinforced Epoxy Nanocomposite. J. of Materi Eng and Perform., 2018, **27**, 5938–5946. https://doi.org/10.1007/s11665-018-3698-7

[5] R. C. L. Tai & Z. Szklarska-Smialowska., Effect of fillers on the degradation of automotive epoxy adhesives in aqueous solutions - Part II The microhardness change and delamination of automotive epoxy adhesives in distilled water and NaCl solutions. J. of Mater Sci., 1993, 28, p 6205–10. doi:10.1007/BF00365045.

[6] R. Kahraman & M. Al-Harthi., Moisture diffusion into aluminum powder-filled epoxy adhesive in sodium chloride solutions. Int. J. of Adhes Adhes., 2005, 25, p 337–41. doi:10.1016/j.ijadhadh.2004.10.003.

[7] S. A. Kumar, M. Alagar & V. Mohan., Studies on corrosion-resistant behavior of siliconized epoxy interpenetrating coatings over mild steel surface by electrochemical methods. J. of Materi Eng and Perform., 2002, **11**, 123–129. https://doi.org/10.1361/105994902770344178.

[8] S. D. Thoppul, J. Finegan & R. F. Gibson.,Mechanics of mechanically fastened joints in polymer-matrix composite structures - A review. Compos Sci Technol, 2009, 69, p 301–29. doi:10.1016/j.compscitech.2008.09.037.

[9] R. J. Moulds & T. R. Baldwin., Toughened adhesives for structural applications. Int. J. of Adhes Adhes., 1983, 3, p 203–7. doi:10.1016/0143-7496(83)90095-7.

[10] K. Kumar, P. K. Ghosh, A. Kumar & O. Singh., Enhanced Thermomechanical Properties of ZrO_2 Particle Reinforced Epoxy Nanocomposite. J. of Materi Eng and Perform.,2021, **30**, p 145–153. https://doi.org/10.1007/s11665-020-05350-3

[11] A. Ozel, B. Yazici, S. Akpinar, M. D. Aydin & Ş. A. Temiz., study on the strength of adhesively bonded joints with different adherends. Compos Part B Eng., 2014, 62, p 167–74. doi:10.1016/j.compositesb.2014.03.001.

[12] N. C. Adak, S. Chhetri, N. H. Kim, N. C. Murmu, P. Samanta & T. Kuila., Static and Dynamic Mechanical Properties of Graphene Oxide-Incorporated Woven Carbon Fiber/Epoxy Composite. J. of Materi Eng and Perform., 2018, **27**, p 1138–1147. https://doi.org/10.1007/s11665-018-3201-5

[13] S. Kirtania & D. Chakraborty., Determination of Thermoelastic Properties of Carbon Nanotube/Epoxy Composites Using Finite Element Method. J. of Materi Eng and Perform., 2018, **27**, p 3783–3788. https://doi.org/10.1007/s11665-017-2981-3

[14] R. Mactabi, I. D. Rosca & S. V. Hoa., Monitoring the integrity of adhesive joints during fatigue loading using carbon nanotubes. Compos Sci Technol, 2013, 78, p 1–9. doi:10.1016/j.compscitech.2013.01.020.

[15] J. H. Tang, I. Sridhar & N. Srikanth., Static and fatigue failure analysis of adhesively bonded thick composite single lap joints. Compos Sci Technol., 2013, 86, p 18–25. doi:10.1016/j.compscitech.2013.06.018.

[16] J. J. Karippal, H. N. Narasimha Murthy, K. S. Rai, M. Krishna & M. Sreejith., Electrical and Thermal Properties of Twin-Screw Extruded Multiwalled Carbon Nanotube/Epoxy Composites. J. of Materi Eng and Perform., 2010, **19**, p 1143–1149. https://doi.org/10.1007/s11665-010-9604-6

[17] J. Shen, W. Huang, L.Wu, Y. Hu & M. Ye., The reinforcement role of different amino-functionalized multi-walled carbon nanotubes in epoxy nanocomposites. Compos Sci Technol., 2007, 67, p 3041–50. doi:10.1016/j.compscitech.2007.04.025.

[18] A. Montazeri A & M. Chitsazzadeh., Effect of sonication

parameters on the mechanical properties of multi-walled carbon nanotube/epoxy composites. Mater Des., 2014, 56, p 500–8. doi:10.1016/j.matdes.2013.11.013.

[19] V. Jain, A. Bisht, S. Jaiswal, K. Dasgupta & D. Lahiri., Assessment of Interfacial Interaction in Graphene Nanoplatelets and Carbon Fiber-Reinforced Epoxy Matrix Multiscale Composites and Its Effect on Mechanical Behavior. J. of Materi Eng and Perform., 2021, **30**, p 8913–8925. https://doi.org/10.1007/s11665-021-06115-2

[20] F. Gardea & D. C. Lagoudas., Characterization of electrical and thermal properties of carbon nanotube/epoxy composites. Compos Part B Eng., 2014, 56, p 611–20. doi:10.1016/j.compositesb.2013.08.032.

[21] D. Zeng, Z. Liu, Z., S. Bai, J. Zhao & J. Wang., Corrosion Resistance of Bis-Silane-Modified Epoxy Coatings on an Al-Zn-Mg-Cu Alloy. J. of Materi Eng and Perform., 2020, **29**, p 5282–5290. https://doi.org/10.1007/s11665-020-05049-5

[22] W. Shen, L. Feng, X. Liu, H. Luo, Z. Liu, P. Tong & W. Zhang., Multiwall carbon nanotubes-reinforced epoxy hybrid coatings with high electrical conductivity and corrosion resistance prepared via electrostatic spraying. Prog Org Coatings., 2016, 90, p 139–46. doi:10.1016/j.porgcoat.2015.10.006.

[23] N. W. Khun, B. C. R. Troconis & G. S. Frankel., Effects of carbon nanotube content on adhesion strength and wear and corrosion resistance of epoxy composite coatings on AA2024-T3. Prog Org Coatings., 2014, 77, p 72–80. doi:10.1016/j.porgcoat.2013.08.003.

[24] S. Yu, M. N. Tong & G. Critchlow., Use of carbon nanotubes reinforced epoxy as adhesives to join aluminum plates. Mater Des., 2010, 31, p S126–9. doi:10.1016/j.matdes.2009.11.045.

[25] N. G. Sahoo, S. Rana, J. W. Cho, L. Li & S. H. Chan., Polymer nanocomposites based on functionalized carbon nanotubes. Prog Polym Sci., 2010, 35, p 837–67. doi:DOI 10.1016/j.progpolymsci.2010.03.002.

[26] J. Zhang, S. Ju, D. Jiang & H. X. Peng., Reducing dispersity of mechanical properties of carbon fiber/epoxy composites by introducing multi-walled carbon nanotubes. Compos Part B Eng., 2013, 54, p 371–6. doi:10.1016/j.compositesb.2013.05.046.

[27] J. B. Bai & A. Allaoui., Effect of the length and the aggregate size of MWNTs on the improvement efficiency of the mechanical and electrical properties of nanocomposites - Experimental investigation. Compos Part A Appl Sci Manuf., 2003, 34, p 689–94. doi:10.1016/S1359-835X(03)00140-4.

[28] L. S. Schadler, S. C. Giannaris & P. M. Ajayan., Load transfer in carbon nanotube epoxy composites. Appl Phys Lett., 1998, 73, p 3842–4. doi:10.1063/1.122911.

[29] S. Cui, R. Canet, A. Derre, M. Couzi & P. Delhaes., Characterization of multiwall carbon nanotubes and influence of surfactant in the nanocomposite processing. Carbon N Y., 2003, 41, p 797–809. doi:10.1016/S0008-6223(02)00405-0.

[30] L. Ci & J. Bai., The reinforcement role of carbon nanotubes in epoxy composites with different matrix stiffness. Compos Sci Technol., 2006, 66, p 599–603. doi:10.1016/j.compscitech.2005.05.020.

[31] P. Laborde-Lahoz, W. Maser, T. Martnez , A. Benito, T. Seeger, P. Cano, R. Guzman de Villoria & A. Miravete., Mechanical Characterization of Carbon Nanotube Composite Materials. Mech Adv Mater Struct., 2005, 12, p 13–9. doi:10.1080/15376490590491792.

[32] G. Gkikas, N. M. Barkoula & A. S. Paipetis., Effect of dispersion conditions on the thermo-mechanical and toughness properties of multi walled carbon nanotubes-reinforced epoxy. Compos Part B Eng., 2012, 43, p 2697–705. doi:10.1016/j.compositesb.2012.01.070.

[33] J-P Jeandrau, C. Peyrac, F. Lefebvre, J. Renard, V. Gantchenko, B. Patamaprohm & C. Guinault., Fatigue Behaviour of Adhesive Joints. Procedia Eng., 2015, 133, p 508–17. doi:10.1016/j.proeng.2015.12.622.

[34] P. K. Ghosh, K. Kumar & A. Kumar., Studies on Thermal and Mechanical Properties of Epoxy-Silicon Oxide Hybrid Materials. J. of Materi Eng and Perform.,2015, **24**, p 4440–4448. https://doi.org/10.1007/s11665-015-1719-3.

[35] G. M. Wu, Y. T. Shyng, S. F. Kung & C. F. Wu., Oxygen plasma processing and improved interfacial adhesion in PBO fiber reinforced epoxy composites. Vacuum., 2009, 83, p S271–4. doi:10.1016/j.vacuum.2009.01.080.

[36] B. R. K. Blackman, A. J. Kinloch & J. F. Watts., The plasma treatment of thermoplastic fibre composites for adhesive bonding. Composites., 1994, 25, p 332–41. doi:10.1016/S0010-4361(94)80003-0.

[37] V. Cooper, A. Ivankovic, A. Karac, D. McAuliffe & N. Murphy., Effects of bond gap thickness on the fracture of nano-toughened epoxy adhesive joints. Polym (United Kingdom)., 2012, 53, p 5540–53. doi:10.1016/j.polymer.2012.09.049.

[38] S. Azari, M. Papini & J. K. Spelt,. Effect of adhesive thickness on fatigue and fracture of toughened epoxy joints - Part I: Experiments. Eng Fract Mech., 2011, 78, p 153–62. doi:10.1016/j.engfracmech.2010.06.025.

[39] D. M. Gleich, M. J. L. Van Tooren & A. Beukers., Analysis and evaluation of bondline thickness effects on failure load in adhesively bonded structures. J Adhes Sci Technol., 2001, 15, p 1091–101. doi:10.1163/156856101317035503.

[40] L. D. R. Grant, R. D. Adams & L. F. M. da Silva., Experimental and numerical analysis of single-lap joints for the automotive industry. Int J Adhes Adhes., 2009, 29, p 405–13. doi:10.1016/j.ijadhadh.2008.09.001.

[41] A. M. Pereira, P. N. B. Reis, J. A. M. Ferreira & F. V.

Antunes., Effect of saline environment on mechanical properties of adhesive joints. Int J Adhes Adhes., 2013, 47, p 99–104. doi:10.1016/j.ijadhadh.2013.08.002

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IMPACT OF CHANGING POLITICAL SCENARIO IN BANGLADESH ON INDIA-BANGLADESH RELATIONS

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1.1 Abstract

This research study examines the impact of Bangladesh's political situation on its relationship with India. After gaining independence in 1971, Bangladesh underwent numerous political changes, sometimes secular, and sometimes more nationalist. It also oscillated significantly between democracy and its inherent 'political volatility.' Whatever else may be said about it, the political situation always has a direct effect on foreign policy. Bangladesh's foreign policy has a direct and significant effect on the bilateral relationship it has with its closest neighbour. The domestic political scene in Bangladesh, dominated primarily by two major parties—the Awami League (AL) and the Bangladesh Nationalist Party (BNP)—has complex diplomatic relations in various ways. The AL, seen as the party friendly toward India, has tried to encourage Bangladesh to offer more options and opportunities for India to be present in Bangladesh, in order to establish connections, facilitate trade, and combat terrorism. The methodology is qualitative, based on policy documents, diplomatic correspondence, scholarly articles, and media reports, to understand how ideologies of leadership and governance models affect bilateral ties. The work also addresses significant issues, including borderland infrastructure, migration, insurgency control, and environmental cooperation. Research indicates that political agreement and a mutual understanding of leadership between New Delhi and Dhaka often result in a strategic partnership and collaborative initiatives. However, if Bangladesh experiences political instability or its leadership decides to whip up anti-India sentiments, or if a third party like China or Pakistan increases its influence over Bangladesh's foreign policy, then the India-Bangladesh partnership may be at risk. This study aims to contribute to the academic and policymaking discussions on India-Bangladesh relations by identifying trends and providing strategic recommendations to ensure that these two countries maintain and strengthen their relationship, regardless of the political changes either country undergoes. The study is particularly concerned with identifying and discussing those kinds of relationship dynamics that might allow for the "diplomatic resilience" necessary for a long-term, meaningful India-Bangladesh relationship.

Keywords: *India-Bangladesh Relations, Political Scenario, Regional Diplomacy, Border Security, Trade Agreements, Bilateral Cooperation, South Asia*

1.2 Introduction

India and Bangladesh share deeply interwoven historical, cultural, and geopolitical ties arising from their shared colonial past and the legacy of the 1971 Bangladesh Liberation War, which, with significant support from India, led to the creation of Bangladesh (Bose, 2011). Since then, the relationship has undergone several phases, characterised by varying degrees of cooperation, trust deficits, and cautious diplomacy. The domestic political scenario has often influenced the trajectory of India-Bangladesh relations, particularly

changes in leadership and policy orientation. Significant rulings by the ruling political party in Bangladesh have historically shaped its foreign policy stance. The Awami League (AL), which has historically been aligned with India's strategic interests, has promoted regional connectivity, economic collaboration, and security cooperation. During the AL's current tenure, landmark agreements such as the 2015 Land Boundary Agreement have been concluded, and interstate insurgency cooperation along the northeastern border has been remarkably strengthened (Pattanaik, 2016). On the other hand, the Bangladesh Nationalist Party (BNP), which has at times adopted a more nationalistic and Islamic orientation, has been perceived as less favourable to India, resulting in diplomatic slowdowns and contentious rhetoric during the BNP's time in power. When the BNP has been in control, interstate dialogues on several issues have progressed at a snail's pace, including river water sharing, border management, and trade balancing. Meanwhile, the cooperation between the Border Security Force (BSF) and the Bangladesh Rifles (BDR) has sometimes been contentious enough to suggest that it ought to be in a courtroom (Riaz, 2013). The political landscape in Dhaka has also affected the (non) fulfilment of a somewhat tantalising set of promises related to river water sharing, border management, and trade balancing (Riaz, 2013). Badminton matches and hockey matches (of the fielding variety) do not make for a good relationship talk and diplomacy do.

1.3 Objectives:

1. To study the changes in the politics of Bangladesh since 2000 and how these changes have impacted the making of its foreign policy.
2. To analyze how shifts in Bangladesh's politics affect India-Bangladesh trade, security, and border relations.
3. To analyze India's diplomatic and strategic responses to these political developments.
4. To present proposals for improving mutually beneficial relations between the two countries in the light of recent changes in the political situation.

1.4 Literature Review:

Rahman, M. (2013). In his study, Rahman investigates the Awami League's (AL) role in enhancing Indo-Bangladesh ties. He underscores, first and foremost, that the Awami League is a party known for its pro-India foreign policy. Second, Rahman elucidates that the AL is a party with a pro-India foreign policy and a clear vision for the sort of dealings it wishes to have with India. Third, he notes that it is a party with a broad agenda, ranging from regional connectivity to cross-border cooperation.

Chakrabarti, S. (2015). Chakrabarti examines India's foreign policy towards South Asia, with a particular emphasis on the strategic geographic location of Bangladesh. He highlights how Bangladesh serves as a crucial transit hub for the northeastern states of India, as well as for regional trade, security, and connectivity projects. He maintains that the stability and political orientation of Bangladesh are crucial to India's engagement strategy in South Asia and makes the case that developments in Dhaka are central to India's neighbourhood diplomacy.

Ahmed, I. (2017). Ongoing concerns in India-Bangladesh relations, such as border security, impact the lives of poor people on both sides of the border. How leadership in either country handles such persistent issues has consequences that directly impact it. In his study, B. A. Ahmed makes a compelling case for examining bilateral relations over time, recognising trends that provide insight into why cooperation occurs or why it does not. He introduces the concept of "bilateral maturity," which describes a relationship where both countries address persistent problems expertly, leading to regional peace and prosperity.

Mitra, S. (2018). Mitra studies the BNP-run governments in Bangladesh and their effect on relations with India. His work links anti-India talk from the BNP with a lack of trust between the two countries. Too much talk from the BNP makes India nervous, and not enough talk

about what India dislikes makes India even more nervous. Mitra's work suggests that the BNP is using nationalism and political rivalry with the Awami League to distract everyone in Bangladesh from real problems and to keep itself in power. Mitra is not impartial. He is very much in favour of India. However, as I suggested in my previous post, his work can serve as a counterpoint to the idea that everything is fine between India and Bangladesh.

Baruah, A. (2020). Baruah assesses the growing tendrils of Chinese influence in Bangladesh's economic and strategic affairs, especially in politically unsettled times. He believes China is investing heavily in Bangladesh and may, in time, gain unprecedented diplomatic and military leverage there. This could remake the neighbourhood, giving China access to the eastern flank of India. It might also compel India to accelerate its strategic investments along its eastern rim—in Bangladesh, Myanmar, and the Andaman Sea—further intensifying the competition between China and India for influence in South Asia.

Hossain, R. (2022). Hossain highlights the growing influence of youth and civil society movements in shaping Bangladesh's foreign policy. His research shows that the narrative public, which now has more avenues to express itself, thanks to social media, can and does affect the decisions of the country's political leaders. Even as those leaders may try to reset the agenda, the youth and civil society can raise new issues as part of the ongoing public conversation. Furthermore, in Hossain's telling, it is the Bangladeshi narrative public that is now very much in the game of foreign policy formation.

1.5 Political Changes in Bangladesh

Since 2000, Bangladesh's political landscape has undergone frequent changes, marked by the rise and fall of power and intense rivalry between the two dominant parties: the Awami League (AL) and the Bangladesh Nationalist Party (BNP). These transitions—and the ideological polarisation that lies at their root—have profoundly influenced both the domestic policies and the foreign policy orientation of the Bangladesh government, especially its relations with India.

The Awami League, renowned for its secular stance and historical association with India dating back to the 1971 Liberation War, has consistently adopted a collaborative approach to dealing with New Delhi. Under the leadership of Sheikh Hasina, the AL has put its signature on a range of bilateral pacts with India, addressing issues such as border demarcation, water-sharing arrangements, power trading, and counter-terrorism (Yasmin, 2020). The political stability that the AL provides has also enabled several large-scale infrastructure projects to transition from the drawing board to the real world, as well as facilitated regional connectivity initiatives, such as the BBIN Motor Vehicle Agreement (Ghosh, 2018).

Conversely, the BNP, which sees itself as a nationalist alternative, has frequently adopted an anti-India stance, especially during election campaigns. When in power, BNP-led administrations have not been particularly keen on bilateral collaboration, especially on sensitive matters such as the Teesta River water-sharing agreement and illegal immigration (Dey, 2017). Alliances with Islamist groups have further complicated and strained Indo-Bangladesh relations, leading to stalled negotiations and border security problems (Sikder, 2015).

American Institute for Bangladesh Affairs. 2019. Democratic Backsliding in Bangladesh. Washington, DC: American Institute for Bangladesh Affairs. Furthermore, the expanding impact of non-governmental actors—chiefly China—has added more layers to an already complex strategic scenario. Both major parties have, in recent years, increasingly turned to Beijing as a source of funding for infrastructure projects and military assistance, in part to counterbalance India's growing influence in the region. This foreign policy, in both its directional and undirected aspects, primarily emerges from the domestic political ideologies of the two parties.

Mass mobilisations and a party-centred governance style mould the political culture of Bangladesh. The recurrence of political violence, frequent hartals, and confrontational legislative behaviour amounts to a form of institutionalised political dysfunction that renders the direction of foreign policy anything but consistent (Begum, 2016). Moreover, when it comes to India, the long-term planning required to make a two-way relationship pay dividends is disrupted by short-term political changes. National elections in Bangladesh frequently serve as an inflexion point in the country's foreign relations. Election campaigning tends to portray India in either a favourable light, calling it a development partner, or a less favourable one, depicting it as a hegemonic neighbour, depending on the framing party's position and electoral strategy. In this way, political transitions in Bangladesh signal events in the country's bilateral engagement with India. Essential for India is to comprehend these shifts so that it can adopt a calibrated approach in dealing with the several successive governments in Dhaka. It is crucial for stable and constructive relations that India aligns its diplomatic strategies with the prevailing political realities on the ground in Bangladesh.

1.6 Impact on Trade and Security

Over the last two decades, trade and security cooperation between India and Bangladesh have evolved in a continuous and largely positive direction. Political stability in Dhaka, especially under regimes friendly to India, like that of the Awami League (AL), has meant that significant advances can be made—covering everything from security collaboration (cooperation to stop terrorism in the border areas) to trade (improve infrastructure and connectivity across the border, which has too often meant border firing, bad for trade and bad for human rights, as well as the economic integration of the two countries).

One of the most noticeable results of political goodwill is the construction of infrastructure that crosses national borders. An example of such an undertaking is the Akhaura-Agartala rail link project. Launched to enhance the efficiency of people-to-people contact and the movement of goods, this relatively modest rail connection reflects a mutual interest in regional connectivity. Such projects are often negotiated and laid down during "honeymoons" in the diplomatic relationship between the two governments concerned. Invariably, they are presented to the public as evidence of the fruitful outcome of the employment of two key nuts in the foreign policy gadget: soft power and political goodwill. The trade relationship has grown much closer, but there is a nagging feeling within the Bangladeshi government that the terms of trade are unfair. Das (2016) reports that the Bangladeshi government frequently raises this issue in discussions with India. At a recent event (20 September 2017) hosted by the Institute for Defence Studies and Analyses, a senior official from the Ministry of Commerce and Industry in Bangladesh took the opportunity to complain about the terms of trade. Until Bangladesh's complaint can be handled to its satisfaction, the trade relationship may be viewed in some quarters as being somewhat unstable.

Regional peace and partnership have led to improved security cooperation under governance in Bangladesh, which prioritises friendship with India. Under the leadership of the Awami League, Bangladesh and India have worked together, much more than ever before, to put a lid on insurgency (and the resultant cross-border violence) associated with northeastern India. The insurgents, of course, tend to find safe havens in places like Bangladesh. So, in the past year (2016)—and with the Awami League now firmly in control of the political space in Bangladesh—we have seen, first, some enhanced security cooperation in northeastern India and then, second, some talks associated with that cooperation at the diplomatic level (for the sake of operational convenience and efficacy). The operational efficiency aspect is important because it means that our operational partners—Bangladesh and India—trust one another. (Trust is in short supply these days.) These meetings between

security and intelligence services associated with Bangladesh and India might, at best, be characterised as something akin to a new kind of partnership—a partner in the region that is friendly. Conversely, illegal migration, smuggling, and insurgent activity tend to rise in hostile political climates, especially when a BNP-led government is in place (Ahmed, 2015). When the Bangladeshi government is non-cooperative or too ideologically divergent from us to be effective, intelligence sharing suffers, and this is directly reflected in compromised border security.

A significant recent success in diplomacy is the Land Boundary Agreement (2015). It was accomplished during a politically cooperative era and resolved a long-standing dispute over enclaves. Better yet, it was a big Step in facilitating better border management. Who would have thought, after all, that landmark agreements are difficult to negotiate in politically fragile times when nationalists are venting much hot air? With Indian investment, economic corridors and special economic zones established in Bangladesh have created jobs, led to the construction of factories, and stimulated growth. However, such growth cannot be taken for granted. It requires something more: the political will, on both sides, to ensure progress. This point is made in a recent essay by Dr. Ehsan. Moreover, he has a good reason for making it. Security issues that straddle national borders significantly impact media representations and public sentiment, which are primarily shaped by the type of political discourse that occurs on both sides of the border. Political cooperation fosters an environment in which diplomatic channels can better serve the public by mitigating unhelpful reporting and facilitating better understanding between the two publics. The two in public can achieve this better if they are well-informed and, better yet, if they agree to keep things under control.Finally, as external powers such as China extend their reach into Bangladesh's infrastructure and defence sectors, India's strategic calculus hinges on how politically amenable Dhaka is to trilateral or multilateral cooperation. A stable government in Bangladesh that is aligned with India is less likely to tolerate excessive Chinese influence, thereby preserving the traditional Indo-Bangladeshi security architecture.

1.7 India's Diplomatic Responses:

A policy of "Neighbourhood First" has always been a mainstay for India, just as it is under Prime Minister Narendra Modi today. Maintaining stable and strong relations with its immediate neighbours is a top priority for India, and that includes Bangladesh. Under this policy, India has prioritised diplomatic outreach to these countries, and in the case of Bangladesh, has worked diligently to engage its government diplomatically. That is the first point. The second point is that India, regardless of which party has been in power, has engaged diplomatically with Bangladesh and sought to promote regional stability, which is rooted in democratic institutions in both countries.

New Delhi's diplomatic strategy has generally taken a course of pragmatic follow-up. It has demonstrated a readiness not only to engage with the deeply polarised protagonists of Bangladesh's domestic politics—the Awami League (AL) and the Bangladesh Nationalist Party (BNP)—but also to work with them in a Bangladesh with improved bilateral relations with India. Prashant Kumar Singh is right to call India's act of courting both parties and working with them in a three-way political alliance a difficult sell. Singh also highlights how Bangladesh's domestic politics often influence India's engagement with Bangladesh (Singh, 2021).

India's restraint in the face of Bangladesh's domestic political crises— including controversial elections and human rights concerns—forms part of a larger strategy to avoid appearing interventionist. This cautious approach helps India maintain long-term influence without direct interference in Bangladesh's sovereignty. High-level visits often signal vibrant diplomatic relations, but joint statements, where regional dynamics allow, also showcase the vibrancy of such relations. Security collaboration, particularly in the context

of counter-insurgency operations and intelligence sharing, is another key aspect of India's stellar performance in Bangladesh.

India has successfully navigated its relations with Dhaka through the recent political turmoil that has affected its neighbour. This has been partly because the ruling coalition in Bangladesh is not entirely averse for India, partly because our neighbor tends to lurch from a period of friendlier political winds to a period of not-so-friendly political winds, and partly because India's delayed-action diplomacy in dealing with the non-state actors, opposition parties, and civil society organisations in Bangladesh has been somewhat effective. It has also been helped along by the fact that India has employed this layered-diplomacy model not just as a means of better understanding the political dynamics in Bangladesh, but also as a way of ensuring political and social resilience in bolstering the bilateral relations between Dhaka and New Delhi, come what political winds may.

1.8 Policy Recommendations

To ensure future-proof and resilient relations between India and Bangladesh, particularly in light of Bangladesh's evolving political landscape, a nuanced, multi-pronged strategy must be adopted. This will require India to move beyond the not-so-different diplomatic style of the previous regime, beyond relying on the style of party-to-party diplomacy, and beyond connecting with Bangladeshi friends who are not just in power now but also with those who will be in power later. Moreover, beyond all the aforementioned methods, there needs to be a move towards building more substantial and genuinely 'people-based' connections.

First, cross-border infrastructure development must remain a priority. Projects such as the Akhaura-Agartala rail link, inland waterway projects, and trans-border electricity trade have already shown positive impacts. India should collaborate with Bangladesh on more such initiatives, for instance, the India-Bangladesh Friendship Pipeline, a natural gas conduit that would run from West Bengal to Dhaka, and the regional road corridors under the BBIN (Bangladesh-Bhutan-India-Nepal) initiative.

Second, cultural diplomacy should be used strategically to reinforce shared heritage and mutual respect. Celebrating Rabindranath Tagore, the 1971 Liberation War, and the Bengali language and literature can create deep emotional and intellectual bonds with Bangladesh. Cultural and intellectual exchanges can elevate that relationship to a higher level. India can do all this by supporting its next-door neighbour in diverse ways.

Third, India must broaden its engagement beyond the ruling party in Dhaka.

Although the Awami League remains a trusted ally, India must also cultivate relations with the other side of the political spectrum in Bangladesh, particularly the BNP. Nonpublic engagement with them could take several forms, including these:

1. Quiet diplomatic outreach to help establish trust and understanding.
2. Academic interactions to deepen knowledge and enrich conversations.
3. Think tank collaborations to broaden the spectrum of policy discussions.

These bridge-building activities could help mitigate the domestic political changes that seem inevitable in Bangladesh, making them less dramatic in terms of their impact on India.

Fourth, people-to-people connections must be strengthened. India should facilitate the visa process for students, medical patients, and skilled professionals from Bangladesh, preferably offering long-term visas. We need to find more ways to make scholarships accessible to deserving young Bangladeshis. Moreover, we should be increasing the production of student exchange programs significantly. Come to think of it, why not also allow our educational institutions to help in the medical sector? That would be a win-win.

Fifth, joint environmental and climate projects offer a non-political platform for bilateral cooperation. India and Bangladesh face similar challenges, including cyclones, that threaten the millions of people living in coastal and riverine areas throughout the two countries. However, where these two neighbours need to work together is in the river basins they

share—especially the Ganges, Brahmaputra, and Meghna River systems, which are among the most densely populated in the world.

Sixth, digital diplomacy and counter-disinformation mechanisms should be established. Social media is increasingly becoming a space where sentiment, both pro and anti, is expressed. During elections or moments of political contention, this is even more true. For a neighbouring country like Bangladesh, this aspect of the expression can directly destabilise the bilateral relationship if falsehoods or half-truths fuel the anti-India sentiment expressed during these moments. So, what to do about it? One viable option is for the Indian side to propose a suite of digital literacy programs to be held in Bangladesh. Why? Because if you are going to tackle a problem in a specific area of human expression, a good place to start is with the human beings who are expressing themselves in that area.

1.9 Conclusion

India must institutionalise bilateral cooperation through robust frameworks such as annual strategic dialogues, trade facilitation councils, and border coordination mechanisms. The bodies should not just comprise government functionaries. They should also include representatives from the private sector and civil society. This would ensure that the India-Bangladesh relationship is not just a function of top-level political dynamics, but one that has, as its foundation, a meaningful set of shared interests that spans all kinds of sectors and communities. In conclusion, India's engagement with Bangladesh needs to be layered and inclusive. The underlying policy must be anchored in mutual growth and interdependence, and in what might be called multi-stakeholder diplomacy. Bangladesh has a domestic politics that can be unstable, and this instability can arise for various reasons, including inter-party squabbles and the always volatile equation between the ruling party and the opposition. However, too much or too little can cause the engagement with Bangladesh to fall off either end of a seesaw.

References

1. Ahmed, F. (2015). *India's Strategic Patience in South Asia*. Journal of Asian Foreign Policy, 11(2), 87–103.
2. Ahmed, K. (2015). *Migration and Border Challenges in India-Bangladesh Relations*. Journal of Border Studies, 12(3), 210–229.
3. Begum, M. (2016). *Partisan Politics and Policy Instability in Bangladesh*. Dhaka University Journal of Political Science, 22(1), 34–56.
4. Baruah, A. (2020). China's Strategic Entry into Bangladesh: Implications for India. *South Asia Monitor*, Issue 158.
5. Bose, S. (2011). *Dead Reckoning: Memories of the 1971 Bangladesh War*. Columbia University Press.
6. Chakrabarti, S. (2015). India-Bangladesh Relations: Post-2014 Challenges. *South Asian Survey*, 22(2), 175–190.
7. Chowdhury, A. R. (2019). Democratic Regression and Party Dominance in Bangladesh. *Asian Affairs*, 50(3), 387–405.
8. Chowdhury, R. (2018). *Media, Politics, and Bilateral Cooperation: The Bangladesh Perspective*. Asian Journal of Political Communication, 5(2), 145–163.
9. Das, K. (2016). *Trade Imbalance Between India and Bangladesh: A Policy Review*. South Asia Economic Review, 8(1), 89–110.
10. Dey, R. (2017). India-Bangladesh Relations: Challenges of the Teesta Water Dispute. *Strategic Studies Journal*, 15(2), 97–113.
11. Dutta, P. (2016). *Cross-Border Security Cooperation: The India-Bangladesh Experience*. Strategic Studies Review, 14(1), 55–72.

12. Ehsan, M. (2020). *India's Investment in Bangladesh: Scope and Political Implications*. Journal of South Asian Studies, 29(2), 172–188.
13. Ehsan, R. (2017). *India and Bangladesh in Regional Organisations: Prospects and Pitfalls*. South Asian Affairs, 9(2), 123–139.
14. Farooq, R. (2019). *Infrastructure Diplomacy: The Case of the Akhaura-Agartala Rail Link*. Bangladesh International Affairs Review, 10(1), 60–78.
15. Ghosh, A. (2019). *Neighbourhood First and the Bangladesh Factor*. Indian Foreign Policy Digest, 6(4), 200–215.
16. Ghosh, P. (2018). *South Asian Connectivity: The BBIN Initiative and Regional Politics*. Observer Research Foundation.
17. Haider, M. (2021). *Vaccine Diplomacy and India's Role in Bangladesh*. Dhaka Global Health Review, 4(1), 44–58.
18. Hossain, R. (2022). *Youth and Civil Society Movements in Bangladesh: Diplomatic Impacts*. Journal of Democratic Studies, 13(2), 98–117.
19. Mitra, S. (2018). *Political Transition and Cross-Border Insurgency in Bangladesh*. Security Review Quarterly, 19(3), 77–92.
20. Nahar, A. (2022). *Elections and National Identity in Bangladesh*. Journal of Asian Political Studies, 31(2), 204–222.
21. Pattanaik, S. S. (2016). India-Bangladesh Relations: Towards a Synergistic Future. *IDSA Issue Brief*.
22. Rahman, M. (2013). *Awami League's India-Centric Foreign Policy Evolution*. International Journal of South Asian Affairs, 8(1), 33–49.
23. Rahman, T. (2020). *India's Silence on Bangladesh's Political Crisis: A Strategic Calculation*. South Asia Monitor, 7(3), 162–174.
24. Riaz, A. (2013). *Political Islam and Governance in Bangladesh*. Routledge.
25. Sikder, S. (2015). *Islamist Alliances in Bangladesh: Implications for India*. Institute of Peace and Conflict Studies Policy Brief.
26. Singh, R. (2022). *Beyond Governments: Engaging Civil Society in India-Bangladesh Relations*. Policy Perspectives, 10(2), 65–80.
27. Sultana, S. (2017). *Counter-Insurgency and Bilateral Security: The India-Bangladesh Model*. Security Studies Quarterly, 14(3), 115–138.
28. Talukdar, B. (2018). *Water Sharing Challenges and the Teesta Deadlock*. Journal of Hydropolitics, 5(3), 110–127.
29. Varma, P. (2022). *China's Strategic Expansion in Bangladesh: Regional Consequences for India*. Strategic Vision, 18(2), 204–219.
30. Vasudevan, R. (2021). China's Strategic Entry into Bangladesh: Implications for India. *South Asia Monitor*, Issue 158.
31. Wadud, M. (2016). *The Land Boundary Agreement: A New Era in India-Bangladesh Relations*. Dhaka Policy Journal, 4(4), 33–47.
32. Yasmin, L. (2020). *Awami League's Foreign Policy: A Tilt Towards India?* Bangladesh Policy Research Forum.

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"Research Highlights"

संत साहित्य में वैकल्पिक आधुनिकता के तत्व

डॉ. अनिल कुमार सिंह*

आधुनिकता (Modernity) एक व्यापक सामाजिक, सांस्कृतिक, बौद्धिक और राजनीतिक प्रक्रिया है, जो यूरोप में पुनर्जागरण (Renaissance), प्रबोधन (Enlightenment), औद्योगिक क्रांति (Industrial Revolution) और वैज्ञानिक सोच के उदय से शुरू हुई मानी जाती है– जो की धीरे–धीरे विश्व के विभिन्न हिस्सों में फैलती चली गई। यह एक ऐसी अवधारणा है जो धार्मिक विश्वासों और परम्पराओं से विमुख होकर परिवर्तन, तर्कशीलता, स्वतंत्रता, विज्ञान और प्रगति की ओर अग्रसर होती है। क्योंकि इस युग के दर्शनिकों जैसे– इमैनुएल काण्ट, ज्याँ पाल सार्त्र, जॉन लाक, हाइडेगर, वोल्टेयर, नीत्से आदि ने व्यक्तिगत स्वतंत्रता, समानता, वैज्ञानिक सोच, तर्क, लैंगिक समानता राजनीतिक लोकतंत्र एवं व्यक्तिवाद के महत्त्व पर बल दिया।

यदि भारतीय परिप्रेक्ष्य में आधुनिकता पर दृष्टि डालें तो भारत में आधुनिकता की परिभाषा केवल पश्चिमी औद्योगिक मॉडल तक ही सीमित नहीं है। यहाँ पाश्चात्य आधुनिकता से लगभग 400 वर्षों पूर्व से ही एक वैकल्पिक आधुनिकता भी सक्रिय है जो ज्ञान, समाज सुधार और आध्यात्मिक चेतना पर आधारित है। यही कारण है कि भारत के संदर्भ में आधुनिकता आंतरिक एवं मूलगत भाव है जिसका एक पक्ष दीर्घकालिक परम्परा और उसके विकास से सम्बन्धित है तो दूसरा पक्ष परिवेश तथा रूप और आकर के परिवर्तन से सम्बन्धित है। इस प्रकार भारत में आधुनिकता एक दोहरी प्रक्रिया रही है– एक ओर परम्परा से टकराव और दूसरी और परम्परा का पुनर्निर्माण। हमें दोनों पर ध्यान देना होगा। वैसे भी किसी कलाकृति का मूल्यांकन एकमात्र सामाजिकता के संदर्भ में करना एकांगी और अवैज्ञानिक होगा। इसलिए हमें प्राचीन और आधुनिक के बीच प्रवाहित उस सूक्ष्म अंतर को पकड़ना होगा जो किसी देश अथवा जाति के समस्त विचारों एवं आदर्शों को अपने में बांधे हुए उस देश की अक्षय निधि के समान सर्वदा वर्तमान रहता है और जिसके समाप्त हो जाने पर वह देश समाप्त हो जाता है।

इस प्रकार भारतीय संदर्भ में आधुनिकता की अवधारणा एक ऐसी अवधारणा है जो अपने मूल मंतव्यों से विचलित हुए बिना समय, समाज और संस्कृति के साथ गतिशील रूप में बदलती रहने वाली अवधारणा है– जो कि पश्चिमी आधुनिकता के एकांगी मॉडल को चुनौती देता है। यह मानता है कि आधुनिकता का कोई एक सार्वभौमिक स्वरूप नहीं हो सकता, बल्कि यह विभिन्न सांस्कृतिक और ऐतिहासिक संदर्भों में भिन्न–भिन्न स्वरूप ग्रहण करती है– जिसे वैकल्पिक आधुनिकता के रूप में जाना जाता है– जो पश्चिमी मॉडल की आधुनिकता के विकल्प के रूप में परम्परागत मूल्यों, दर्शन, समुदायिकता और आध्यात्मिकता को आधुनिक विचारों जैसे– समानता, स्वतंत्रता और सामाजिक न्याय के साथ जोड़ने का प्रयास करती है।

भारतीय संत साहित्य विशेष रूप से मध्यकालीन भक्तिकाव्य के सामाजिक, सांस्कृतिक व दार्शनिक आयामों का विश्लेषण करने पर प्राप्त होता है कि संत साहित्य इस वैकल्पिक आधुनिकता का जीवंत उदाहरण प्रस्तुत करता है। मध्यकालीन भारत में संत कवियों जैसे– कबीर, गुरुनानक, संत रविदास, सूरदास, तुलसीदास, मीरा, तुकाराम आदि ने अपनी रचनाओं के माध्यम से सामाजिक सुधार, आध्यात्मिक जागरूकता और मानवीय मूल्यों को बढ़ावा दिया। इन संतों ने न केवल धार्मिक एवं सामाजिक रूढ़ियों को चुनौती दी, बल्कि एक ऐसी वैचारिक जमीन तैयार की जो आज के संदर्भ में वैकल्पिक आधुनिकता के रूप में देखी जाती है।

ऐतिहासिक दृष्टि से देखें तो संत साहित्य का उद्‌भव, विकास एवं चरम 13वीं शताब्दी से 17वीं शताब्दी के बीच प्राप्त होता है जिसे मध्यकालीन भारत के नाम से जाना जाता है– और यह एक ऐसा दौर था जिसमें सर्वत्र सामाजिक, धार्मिक और राजनीतिक उथल–पुथल प्राप्त होता है। इस काल में जातिगत भेदभाव, धार्मिक कट्टरता और सामंती शोषण चरम पर था। संत साहित्य इस पृष्ठभूमि में एक सामाजिक और आध्यात्मिक क्रांति के रूप में उभरा। यह संत साहित्य न केवल धार्मिक था बल्कि सामाजिक सुधार और समानता की भावना से भी ओत–प्रोत था। इस प्रकार वैकल्पिक आधुनिकता के आलोक में संत साहित्य का

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मंथन करने पर हमें विशेषता के रूप में कुछ महत्वपूर्ण बिन्दु प्राप्त होते हैं जिनके आलोक में हम वैकल्पिक आधुनिकता और संत साहित्य के अन्तर्सम्बन्धों को ठीक–ठीक जान सकते हैं। ये बिन्दु निम्नवत् हैं–

(i) सामाजिक समानता का उद्घोष
(ii) बहुलता में समावेशन का अद्भुत प्रयास
(iii) श्रम का आध्यात्मिक महत्व
(iv) भाषा का लोकतंत्रीकरण
(v) लोक संस्कृति को महत्व
(vi) लौकिकता और निर्गुण भक्ति
(vii) पर्यावरणीय चेतना
(viii) लैंगिक और जातिगत न्याय

संत साहित्य भारतीय साहित्य की वह शाखा है जो भक्ति, मानवता और सामाजिक चेतना से परिपूर्ण है। यह साहित्य केवल धार्मिक उपदेशों तक सीमित नहीं है, बल्कि इसमें गहरे सामाजिक सरोकार भी निहित है। संत कबीर, संत रविदास, संत नामदेव, संत तुकाराम, गुरुनानक, मीराबाई आदि संतों ने अपने समय की सामाजिक विसंगतियों, जातिवाद, छुआछूत, धार्मिक पाखंड और अन्याय के विरुद्ध आवाज उठाते हुए समाज को एक नई दिशा देने का सराहनीय प्रयास किया। इन सामाजिक विसंगतियों में भी संत साहित्य में जातिवाद एवं छुआछूत का विरोध प्रमुख रहा है। कबीर ने इसका तीखा विरोध करते हुए कहा है कि–

उलटि जात–कुल दोऊ विसारी। सुन्न सहज महि बुनत हमारी।।
पंडित मुल्ला जो लिखि दीया। छाड़ि चले हम कछू न लीया।।[1]

× × × ×

ऐसा भेद बिगूचन भारी।
बेद–कतेब दीन अरू दुनियां, कौन पुरुष कौन नारी।
एक बूँद एकै कल–मूतर एक चाम एक गूदा।
एक जोति थैं सब उत्पन्ना को बाह्मन को सूदा।।[2]

संत रविदास जो स्वयं दलित जाति से थे, कहते हैं– ''मन चंगा तो कठौती में गंगा''– अर्थात आत्मा की पवित्रता किसी जाति या जन्म से नहीं, बल्कि मन की भावना से होती है। इसलिए इन संतों ने मंदिर–मस्जिद, पूजा–नमाज़ जैसे वाह्यचारों के स्थान पर अंतरात्मा की शुद्धि पर बल दिया– संत रविदास की उक्ति है–

''तोडूं न पाती, पूजूं न देवा
बिन पत्थर, करें रैदास सहज सेवा।''

अर्थात बिना किसी फूल–माला, पत्तियाँ तोड़े बिना, न ही किसी देवता की पूजा करे बिना, न ही इन पत्थरों के भगवान को पूजे बिना– अर्थात पूजा, कर्मकाण्ड के बिना इंसान को केवल सत्य कर्म करते हुए मानवता की सहज सेवा करनी चाहिए। संसार में प्रेम, भाईचारा, नैतिकता व मानवता ही सबसे बड़ी पूजा या सेवा है।

इस प्रकार संत साहित्य केवल आध्यात्मिक साधना का साधन नहीं है, बल्कि सामाजिक चेतना का वाहक भी है। इसमें समाज की पीड़ा, जनमानस की आकांक्षाएँ और समानता का भाव निहित है। संत कवियों ने अपने साहित्य के माध्यम से सामाजिक विसंगतियों के विरूद्ध निडर होकर आवाज उठाई और एक ऐसे समाज की कल्पना की जो– प्रेम, समता, सहिष्णुता और मानवता पर आधारित है। आज के समय में जब समाज फिर से जातिवाद, सांप्रदायिकता, सामाजिक असमानता और नैतिक पतन जैसी चुनौतियों से जूझ रहा है ऐसे में संत साहित्य के सामाजिक समता के स्वर आज फिर से प्रासंगिक को उठे हैं क्योंकि संतों का सामाजिक समता का उद्घोष एक ऐसा यथार्थ और कालजई सत्य है जो युगों–युगों तक समाज को दिशा देता रहेगा।

वैकल्पिक आधुनिकता की तलाश के क्रम में संत साहित्य में जो दूसरी महत्वपूर्ण बात प्राप्त होती है, वह है– बहुलता में समावेशन का अद्भुत प्रयास। क्योंकि संत साहित्य का मूल संदेश ही यह है कि– ''सब में एक परमात्मा है''–

इस घट अन्तर बाग बगीचे, इसी में सिरजन हारा।
इस घट अन्तर सात समुन्दर, इसी में नौ लख तारा।

कहत कबीर सुनो भाई साधो, इसी में साईं हमारा।।[3]

यह दृष्टिकोण मानव–मानव के भेद को मिटाता है। पुनः संत रविदास की उक्ति है–

''ऐसा चाहूँ राज मैं जहाँ मिलै सबन को अन्न।
छोट–बड़ो सब सम बसै रविदास रहै प्रसन्न।।

यह एक ऐसे आदर्श समाज की परिकल्पना है जिसमें कोई भेद नहीं है– ऐसा समाज जिसमें सभी को समान अधिकार एवं सुविधाएँ प्राप्त हो। बहुलता में समावेशन हेतु ही संत साहित्य में सहिष्णुता, धर्मनिरपेक्षता और सर्वधर्म समभाव की झलक सर्वत्र मिलती है। कबीर और गुरु नानक ने हिंदू–मुस्लिम एकता पर काफी बल दिया है–

''हिन्दू कहत है राम हमारा मुसलमान रहमाना
आपस में दोऊ लड़े मरतु हैं मरम कोई नहिं जाना।'[4]
× × × ×
पूरब दिशा हरी कौ बासा पच्छिम अलह मुकामा
दिल में खोज दिलहिं में खोजौं इहैं करीमा रामा।[5]

संत साहित्य में वैकल्पिक आधुनिकता की तलाश के क्रम में हम पाते हैं कि संत साहित्य न केवल धार्मिक और आध्यात्मिक दृष्टि से समृद्ध है बल्कि इसमें सामाजिक यथार्थ और श्रम की महत्ता को भी अत्यंत गहराई से रेखांकित किया गया है। संत कवियों ने अपनी वाणी के माध्यम से आमजन की पीड़ा और उनके श्रम के प्रति सम्मान का भाव प्रस्तुत किया है– इस प्रकार इसमें शोषित, वंचित, दलित और श्रमिक वर्ग की आवाज़ को स्थान मिला है और उनके श्रम को सामाजिक गरिमा प्राप्त हुई। यहाँ श्रमिक वर्ग को न केवल स्थान मिला बल्कि श्रम को आध्यात्मिक साधना के समान माना गया है। यह संत समाज की न केवल क्रांतिकारी बल्कि अति आधुनिक सोच कहीं जा सकती है।

कबीर स्वयं जुलाहा थे। उन्होंने स्पष्ट रूप से स्वीकार किया है– ''करनी कर हाथ चलावै, जिह्वा राम नाम दुहरावै''– अर्थात श्रम करते हुए भी मनुष्य ईश्वर स्मरण कर सकता है। कबीर साहित्य में कर्म और श्रम को योग के समान बताया गया है। कबीर के अतिरिक्त संत रविदास, संत नामदेव, संत तुकाराम भी ऐसे संत थे जो श्रमिक जीवन जीते हुए भी भक्ति की ऊँचाइयों को छुए और श्रमशीलता को सम्मानित किए। संत साहित्य में श्रम से अर्जित अन्न को पवित्र एवं श्रेष्ठ माना गया है तथा कहा गया है कि श्रम और भक्ति में कोई भेद नहीं है। साथ ही यहाँ यह भी ध्यातब्य है कि कार्ल मार्क्स से लगभग 400 वर्ष पूर्व ही संत कवियों ने एक ऐसे वर्गहीन समाज की कल्पना कर ली थी जहाँ न कोई ऊँच है न कोई नीच– ''जाति न पूछो साधु की पूछ कीजिए ज्ञान''– कबीर की यह उक्ति साफ–साफ कहती है कि सभी मानव समान है और श्रमिक चाहे किसी जाति का हो वह समाज की रीढ़ है। इस प्रकार हेय दृष्टि से देखे जाने वाले श्रमिक वर्ग को संत कवियों ने सामाजिक न्याय और आत्म सम्मान दिलाने की चेष्टा की। क्योंकि संत साहित्य का सार ही है कि– ''जो श्रम करता है वही धर्म करता है।''

संत साहित्य में न केवल पुरुष श्रम बल्कि स्त्री श्रम को भी स्वीकार किया गया है। मीराबाई ने आत्म अनुभूति के साथ भक्ति की राह पर तमाम अवरोधों के बाद भी चलकर यह साबित कर दिया कि स्त्री भी सामाजिक बंधनों से ऊपर उठकर आध्यात्मिक पथ पर चल सकती है। इन संतों के श्रम से सम्बन्धित ये विचार न केवल तत्कालीन समय में बल्कि आज भी उतने ही प्रासंगिक हैं, विशेषकर उस दौर में जब समाज में आर्थिक विषमता और श्रम की उपादेयता देखने को मिलती है।

भाषा की दृष्टि से संत साहित्य पर विचार करें तो प्राप्त होता है कि संतों की भाषा नीति अत्यंत आधुनिक उदार एवं सूझबूझ से भरी हुई है। संत कवियों को यह ठीक–ठीक ज्ञान था कि व्यापक जन समुदाय से उन्हीं की भाषा और भावनाओं के माध्यम से जुड़ा जा सकता है। इसीलिए गोस्वामी तुलसीदास ने काव्य साधना हेतु संस्कृत का प्रकाण्ड विद्वान होते हुए भी भाषा में श्री रामचरितमानस लिखने का निर्णय किया जबकि पंडित लोगों में उस समय भाषा का आदर नहीं था। गोस्वामी जी ने स्वीकार किया है कि–

''भाषा भानिति भोरि मति मोरी।
हँसिबे जो हँसे नहिं खोरी।।''[6]

इस प्रकार गोस्वामी जी ने पंडितों की हँसी की परवाह नहीं की, क्योंकि वे जानते थे कि वही वस्तु मानास्पद होती है जो उपयोगी भी हो। जो वस्तु किसी के काम ही ना आए उसका मूल्य ही क्या? पुनः कबीर तो स्पष्ट रूप से स्वीकार करते हैं कि–

बोली हमरी पूरब की, हमें लखै नहिं कोय।
हमको तो सोई लखे, जो धुर पूरब का होय।।[7]

तुलसी और कबीर के अतिरिक्त अन्य संतों की भाषा पर विचार करें तो प्राप्त होता है कि संत कवियों ने परम्परागत विद्या–सत्ता (संस्कृत, अरबी, फारसी) से हटकर लोक भाषा– अवधी, ब्रज, राजस्थानी, पंजाबी, मराठी, भोजपुरी, गुजराती को काव्य रचना का माध्यम बनाया जिसके कारण ज्ञान का केंद्र शास्त्र पाठकों से हटकर जनता के बीच पहुँच गया। इसे हम भाषा के लोकतंत्रीकरण की प्रेरणा के रूप में भी देख सकते हैं जिसके द्वारा इन संत कवियों ने ज्ञान के केंद्रीयकरण को तोड़ने का पूरा प्रयास किया। अपनी इसी लोक भाषा के माध्यम से संतों ने जनता से सीधे संवाद किया और समाज में व्याप्त कुरीतियों को उजागर किया। वास्तव में लोक भाषा नें संत साहित्य को सामाजिक परिवर्तन का एक सशक्त माध्यम बना दिया।

लोक भाषा के अतिरिक्त यदि लोक संस्कृति पर विचार करें तो संत साहित्य और लोक संस्कृति एक–दूसरे के पूरक दिखाई देते हैं। संतों ने लोक संस्कृति को अपनी रचनाओं में स्थान देकर उसे संजीवनी दी और लोक संस्कृति ने संत साहित्य को जन–जन तक पहुँचाने का माध्यम बनकर उसको कालजई बना दिया। लोक संस्कृति से जुड़ाव का एक मुख्य कारण यह भी था कि संत साहित्य कोई दरबारी साहित्य नहीं था, बल्कि गाँव के चौपाल, मंदिर और घर–आंगन में पनपने वाला साहित्य है। यही कारण है कि संत साहित्य का एक बड़ा हिस्सा भजन और कीर्तन के रूप में है। संत तुकाराम, मीराबाई, रविदास, सूरदास, नामदेव व कबीर के भजन आज भी लोक गायकों द्वारा गाए जाते हैं।

संत साहित्य की विशेषता यह है कि उसमें लौकिकता और निर्गुण भक्ति दोनों का अत्यंत प्रभावशाली समन्वय प्राप्त होता है। संत कवियों ने निर्गुण की व्याख्या करते हुए, सामाजिक यथार्थ को भी सामने रखा। इसलिए कबीर की वाणी में निर्गुण भक्ति के साथ–साथ सामाजिक विषमताओं, पाखण्डों और जातीय ऊँच–नीच पर तीखा व्यंग्य मिलता है। संत रविदास एक दलित संत कवि होने के कारण न केवल निर्गुणता को समझा बल्कि सामाजिक न्याय और आत्मसम्मान की भी बात की है। पुनः दादू दयाल ने भी निर्गुण ब्रह्म की बात करते हुए संप्रदायों की आलोचना की और आंतरिक साधना को प्राथमिकता दी। गुरु नानक ने भी 'इक ओंकार'– ईश्वर एक है– के द्वारा समत्व का घोष करते हुए अपने समय की प्रचलित जाति व्यवस्था और सामाजिक विभाजन को चुनौती दी तथा प्रत्येक व्यक्ति की अंतर्निहित गरिमा और मूल्य की वकालत की। इस प्रकार हम कह सकते हैं कि मध्यकालीन संतों ने निर्गुण–सगुण विवाद को लोकानुभव केंद्रित– 'साक्षात ईश्वर बोध' में रूपांतरित कर दिया।

पुनः गुरु नानक का 'इक ओंकार' इस अर्थ में भी अतिमहत्वपूर्ण एवं आधुनिक दृष्टि संपन्न है कि यह केवल मानवीय सीमाओं तक सीमित नहीं है बल्कि संपूर्ण सृष्टि को अपने में समाहित करता है। इसके अनुसार ईश्वरीय उपस्थित न केवल मनुष्यों में बल्कि प्राकृतिक जगत जिसमें पशु, पौधे और पर्यावरण भी शामिल है, में व्याप्त है। यह समग्र दृष्टिकोण लोगों में प्रकृति के प्रति गहरी श्रद्धा विकसित करने और पृथ्वी के संरक्षक के रूप में कार्य करने के लिए प्रेरित करता है। संत तुकाराम तो अपने अभंगों (भक्ति रचनाओं) में यहाँ तक कह देते हैं कि– ''वृक्ष वल्ली अम्हां सोयरे वनचरे''– अर्थात् पेड़–पौधे और वन्य जीव हमारे सगे सम्बन्धी हैं, परिवार के समान है, हमारे जीवन के अभिन्न अंग हैं। हमें प्रकृति के प्रति आभार और प्रेम रखना चाहिए। प्रकृति और जीव–जंतु केवल संसाधन नहीं, बल्कि हमारे सजीव साथी हैं। हमें इन्हें सहेजना और इनकी रक्षा करनी चाहिए ताकि जीवन चक्र संतुलित बना रहे। गुरु नानक और संत तुकाराम के साथ ही कबीर ने भी पेड़–पौधे, जल, वायु, नदी, पहाड़ का न केवल उल्लेख किया है बल्कि इन्हें ईश्वर का रूप माना है। कबीर के अनुसार तो–

''पाती तोरै मालिनी पाती–पाती जीउ।''[8]

अर्थात प्रत्येक पत्ती में जीवों का निवास है अतः उसे अनावश्यक नुकसान नहीं पहुँचाना चाहिए। कबीर की दृष्टि से पेड़–पौधे, नदी, पहाड़, पृथ्वी सभी परमार्थ हेतु हैं– अतः ये सदैव बने रहने चाहिए–

वृक्ष कबहुँ नहिं फल भखै, नदी न संचै नीर।
परमारथ के कारने साधुन धरा सरीर।।[9]
सबकी उतपति धरती सब जीवन प्रतिपाल।
धरती न जाने आप गुन ऐसा गुरु बिचार।।[10]

परन्तु कबीर यहीं नहीं रुकते, वे तो इससे भी आगे बढ़कर प्रकृति को नुकसान पहुँचाने वाले लोगों को चेतावनी देते हुए कहते हैं कि–

बकरी पाती खात है ताकी काढ़ी खाल।
जो नर बकरी खात हैं ताको कौन हवाल।।[11]

इस पर्यावरणीय चेतना के अतिरिक्त संत साहित्य के आईने में वैकल्पिक आधुनिकता के चित्र में हमें जो अंतिम और अति महत्वपूर्ण विशेषता प्राप्त होती है वह है– लैंगिक और जातिगत समानता का विचार। संत साहित्य में स्त्री को देवी स्वरूप माना गया है। मीराबाई जैसी संत कवियित्री ने अपने समय की सभी सामाजिक मर्यादाओं को तोड़कर आध्यात्मिक मुक्ति का मार्ग चुना–

जग सुहाग मिथ्या री सजनी हांवा हो मिट जासी।
वरन् कर्यां हरि अविनाशी म्हारो काल–व्याल न खासी।।[12]

पुनः इस संदर्भ में गुरुनानक की उक्ति है कि–

सो क्यों मन्दा आखिए, जित जमीं राजान्[13]

अर्थात् उस स्त्री को तुच्छ क्यों कहें जिससे राजा तक जन्म लेते हैं। इस लैंगिक समानता के अतिरिक्त संत कवियों ने वेद–पुराण आधारित जाति–जटिलता, पितृसत्ता एवं संस्कृतभिजात्य पर तीखा प्रहार किया। संत रविदास ने तो 'बेगमपुरा' की कल्पना कर शोषण रहित नगर का स्वप्न रचा जिसे आधुनिक लोकतांत्रिक आदर्शों की पूर्वपीठिका कहा जा सकता है। संत रविदास की जातिभेद के विरुद्ध प्रसिद्ध उक्ति है–

रैदास एक ही बूँद से भयो सब विस्तार।
मूर्ख है जो करे वर्ण–अवर्ण विचार।।

इस प्रकार इन संतों ने भक्ति को कर्मकाण्ड से परे लिंग व जाति भेद विरहित लौकिक–परमार्थी प्रेम–संबंध के रूप में व्याख्यायित किया है।

अस्तु निष्कर्ष के रूप में हम कह सकते हैं कि पश्चिमी आधुनिकता जहाँ वैज्ञानिक, तर्क, तकनीक व राज्य केन्द्रित है वहीं संत साहित्य अनुभव, आध्यात्म, भाषा–सामांजस्य और सामाजिक समता पर आधारित है। अतः स्पष्ट है कि संत साहित्य के परिप्रेक्ष्य में वैकल्पिक आधुनिकता न तो परम्परा का अंधानुकरण है और न ही पश्चिमी आधुनिकता की नकल; बल्कि यह परम्परा और आधुनिकता के बीच एक अनूठा संवाद है जो स्थानीय ज्ञान–परम्पराओं को आधुनिक चुनौतियों के समाधान के लिए उपयोग करता है और जो अपने आप में सम्पूर्ण विश्व में अनूठा, अद्वितीय, चिरन्तन सत्य स्वरूप है।

संदर्भ ग्रंथ सूची–

1. कबीर, हजारी प्रसाद द्विवेदी, पृष्ठ 229, राजकमल प्रकाशन, नई दिल्ली, पटना
2. कबीर, हजारी प्रसाद द्विवेदी, पृष्ठ 239, राजकमल प्रकाशन, नई दिल्ली, पटना
3. वहीं, पृष्ठ 184
4. वहीं, पृष्ठ 248
5. वहीं, पृष्ठ 210
6. श्री रामचरितमानस, बालकाण्ड, चौपाई संख्या–147
7. फकीर, हजारी प्रसाद द्विवेदी, पृष्ठ 224
8. संत कबीर, डॉ. रामकुमार वर्मा, पद–14, पृष्ठ 104
9. कबीर दोहावली, दोहा संख्या–912
10. 'बीजक विवेक प्रकाशिनी' (बीजक टीका), साध्वी–ज्ञानचंद जी, श्री कबीर ज्ञान प्रकाशन केंद्र, झारखंड, दोहा संख्या–201, पृष्ठ 478
11. हिंदी साहित्य का इतिहास, रामचंद्र शुक्ल, भक्तिकाव्य, पृष्ठ–46, प्रयाग पुस्तक सदन, इलाहाबाद।
12. हिंदी साहित्य का इतिहास, सं0 डॉ0 नगेंद्र, पृष्ठ–221, नेशनल पब्लिशिंग हाउस, नई दिल्ली
13. श्री गुरुग्रन्थ साहब, पृष्ठ–473

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Synthesis, antifungal, antileishmanial evaluation, and molecular docking study of some 3-(4-((chlorobenzyloxyphenyl)aminomethyl)quinazolin-4(3*H*)-ones

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ABSTRACT A series of 3-(4-((chlorobenzyloxyphenyl)aminomethyl)quinazolin-4(3*H*)-ones **2(a-j)** was synthesized by aminomethylation of quinazolin-4(3*H*)-one (**1**) and 2-phenylquinazolin-4(3*H*)-one (**1a**) with 4-(chlorobenzyloxy)anilines in the presence of formaldehyde. All the synthesized compounds were screened for their *in vitro* antifungal activity against human pathogenic fungi and for *in vitro* antileishmanial activity against *Leishmania donovani* promastigotes. In addition, molecular docking was performed for compounds such as **2a, 2d, 2i**, and **2j.**

KEY WORDS Quinazolinone, Antifungal activity, Antileishmanial activity, Molecular docking

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INTRODUCTION

In the past few decades, the fungal infectious diseases have developed increased resistance to the most popular antifungal drugs belonging to many chemical entities for the treatment of patients. Fungal infections are very harmful for human beings, with a weakened immune system destroyed by cancer, human immunodeficiency virus or other diseases. Hence, the discovery and development of new antifungal agents are required, which explore novel mechanism of action and efficient bioactive frameworks.

Further, Leishmaniasis is one of the most neglected tropical diseases worldwide. It is the second biggest parasitic killer in the world, after malaria, and caused by an intracellular protozoan of the genus *Leishmania* with a huge impact on human health. Its global impact and severity of the infection are mainly found in Asia, the Middle East, North Africa, East Africa, the Mediterranean, and South and Central America. Leishmaniasis has affected over 12 million people in worldwide. In addition, 350 million are at risk of infection. The treatments of Leishmaniasis have been challenging and many people depend upon compounds with toxic side effects. Leishmaniasis is caused by over 20 species of parasites; hence use of the same cure regimens in multiple regions is difficult.[1-3]

The huge amount of available data on the chemical characteristics and biological activity of quinazolin-4-(3*H*)-ones proved that it has a significant position in medicinal chemistry. Quinazolin-4-(3*H*)-one derivatives have attracted lots of attention because of their versatile biological properties such as antibacterial,[4] antifungal,[5-10] anticancer,[11,12] insecticidal,[13] anti-inflammatory,[14] antimalarial,[15] and antileishmanial activities.[16-18]

According to this standpoint, we have designed and synthesized a series of 3-(4-((chlorobenzyloxyphenyl) aminomethyl)quinazolin-4(3*H*)-ones **2(a-j)**. The synthesized compounds were screened for their *in vitro* antifungal activity

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against human pathogenic fungi and *in vitro* antileishmanial activity against *Leishmania donovani* by using standard drugs *fluconazole* and *pentamidine,* respectively. A molecular docking study was also undertaken to identify the behavior of molecules and binding sites of the target protein and compared to the standard drug fluconazole.

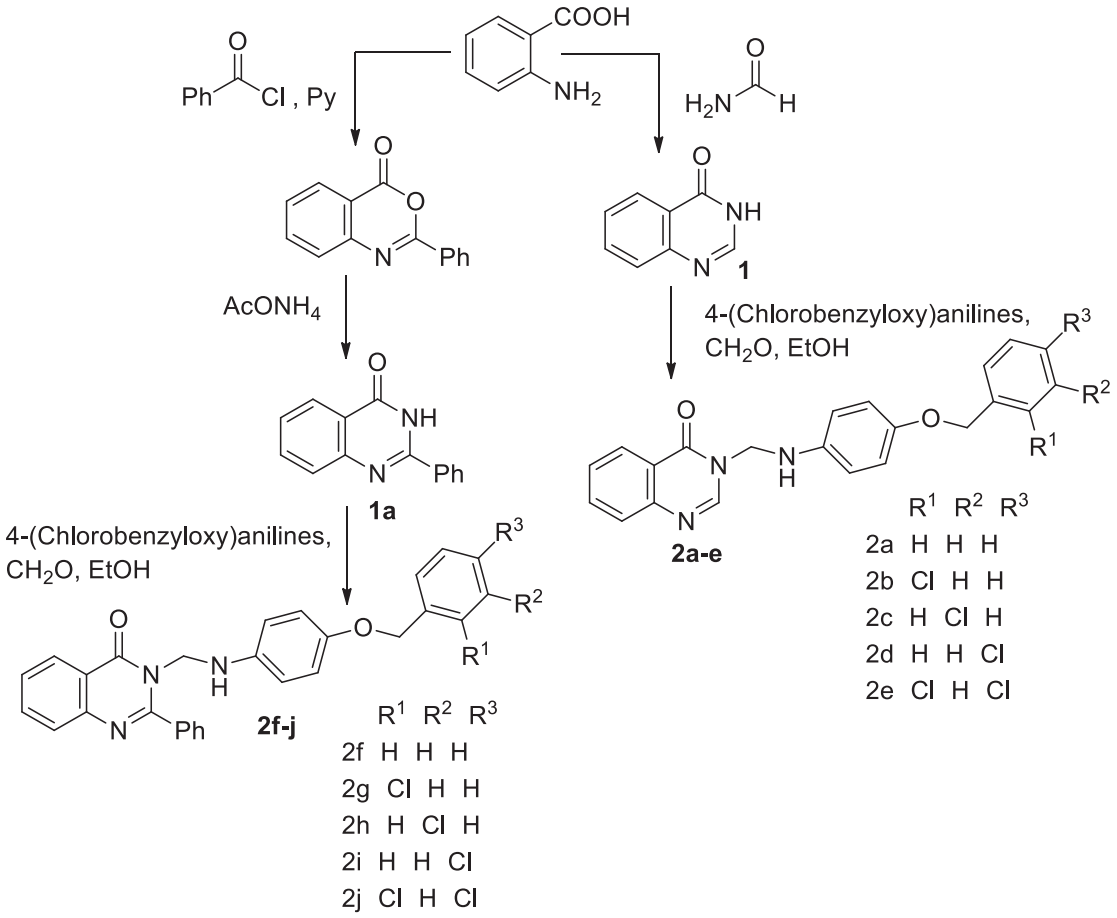
RESULTS AND DISCUSSION

Chemistry

The synthesis of targeted quinazoline derivatives **2a-j** was achieved through a linear synthetic route using a suitably modified reported method.[19] Each step was carefully optimized to ensure efficiency and reproducibility. Initially, the 2-aminobenzoic acid on reaction with formamide under reflux conditions afforded quinazolin-4(3*H*)-one (**1**). 2-Phenylquinazolin-4(3*H*)-one (**1a**) was also prepared by the reaction of 2-aminobenzoic acid with benzoyl chloride in pyridine, followed by the fusion with ammonium acetate.[20] Quinazolin-4(3*H*)-one (**1**) and 2-phenylquinazolin-4(3*H*)-one **(1a)** on aminomethylation with 4-(chlorobenzyloxy) anilines in the presence of formaldehyde gave 3-[{4-(benzyloxy)phenyl}aminomethyl]quinazolin-4(3*H*)-ones **2(a-e)** and 3-[{4-(benzyloxy) phenyl}aminomethyl]-2-phenylquinazolin-4(3*H*)-ones **2(f-j),** respectively, in good yields. Physical data of the compounds 2(a-e) and 2(f-j) have been summarized in the **Table 3.**

Antifungal activity

Compounds **2(a-j)** were screened for their *in vitro* antifungal potential against human pathogenic yeast, namely, *Candida albicans*, *Cryptococcus neoformans*, *Candida parapsilosis,* and mycelial fungi, namely, *Trichophyton mentagrophytes* and *Aspergillus fumigatus*. They were tested at 100 µg/mL concentration in DMSO by Macrobroth two-fold serial dilution techniques in Sabouraud's Dextrose Broth. The spore suspension of 10^5 spores/mL was used for this purpose. The drug dilutions were made serially. The test was performed at 29°C, and minimum inhibitory concentration (MIC) in µg/mL was recorded by visual observation after 24–72 h. The details of the *in vitro* antifungal activity profile of the compounds are summarized in Table 1. Among the aminomethylated quinazolin-4-(3*H*)-ones **2(a-e)**, compound **2a** with 4-(benzyloxy)-anilinomethyl group showed MIC 6.25 µg/mL against TM and AF while compounds **2d** and **2e** having 4-(4-chlorobenzyloxy)-anilinomethyl and 4-(2, 4-dichlorobenzyloxy)-anilinomethyl group, respectively, showed MIC 3.12 µg/mL against TM and AF. Compound **2d** also showed MIC 6.25 µg/mL against CA. Out of five aminomethylated 2-phenyl quinazolin-4-(3*H*)-ones **2(f-j)**, compounds **2i** and **2j** both having 4(4-chlorobenzyloxy)-anilinomethyl and 4-(2,4-dichlorobenzyloxy)anilinomethyl groups, respectively, showed MIC 6.25 µg/mL against CA, and MIC 3.12 µg/mL against TM and AF. From the



Scheme: 3-(4-((chlorobenzyloxyphenyl)aminomethyl)quinazolin-4(3*H*)-ones (2a-j)

Table 1: Minimum inhibitory concentration (µg/mL) of compounds against Pathogenic fungi by the Macrobroth Two-Fold Serial Dilution Technique

Compd. No.	*Candida albicans* (CA)	*Cryptococcus neoformans* (CN)	*Candida parapsilosis* (CP)	*Trichophyton mentagrophytes* (TM)	*Aspergillus fumigatus* (AF)
2a	>100	>100	>100	6.25	6.25
2b	50	>100	>100	50	50
2c	50	>100	>100	50	50
2d	6.25	>100	>100	3.12	3.12
2e	50	>100	>100	3.12	3.12
2f	25	>100	>100	3.12	3.12
2g	25	>100	>100	50	50
2h	25	>100	>100	50	50
2i	6.25	>100	>100	3.12	3.12
2j	6.25	>100	>100	3.12	3.12
Fluconazole	0.50	1.0	2.0	1.0	2.0

antifungal activity data, it is clear that the introduction of phenyl substitution at the 2nd position in quinazolin-4-(3*H*)-one does not play any major effect on the biological potential of aminomethylated quinazolin-4-(3*H*)-ones.

Antileishmanial activity

Compounds **2(a-j)** were also tested for their *in vitro* Antileishmanial activity against *L. donovani* promastigotes and antileishmanial activity data are summarised in Table 2. Compounds showed 40–56% inhibition of *L. donovani*. There was no specificity regarding substitution at the 2nd position in quinazolinone. Both quinazolinones having a hydrogen at the 2nd position and phenyl substitution at the 2nd position, showed the same trend in terms of Antileishmanial activity. None of the compounds was found to be comparable to the standard drug Pentamidine, which showed 100% inhibition of *L. donovani*. No SAR could be established. In both cases, benzyloxyphenylaminomethyl and 2,4-dichlorobenzyloxyphenylanilinomethyl groups showed a decrease in biological potential.

Molecular docking analysis for antifungal activity

To find out the orientation, mode of binding between the target protein and 3-(4-((chlorobenzyloxyphenyl) aminomethyl)quinazolin-4(3*H*)-one derivatives for antifungal activity, we have performed molecular docking by using the MGL tool. The 3D structure of the protein (PDB: 6AKZ) was retrieved from the protein data bank and the ligand structure was optimized by using Gaussian 9.0 software. Out of ten synthesized compounds (**2a-2j**), the docking simulation was carried out for **2a, 2d, 2i,** and **2j**. The 3D and 2D molecular docking interactions of compounds **2a, 2d, 2i, 2j,** and fluconazole were displayed in Figures 1-5, respectively.

The lowest docking score of **2a** was found to be -8.1 kcal/mole. It shows conventional hydrogen bond interaction with PHE156, LYS154, aromatic interaction with TYR157, hydrophobic interaction with GLN447, LYS161, and Vander waal's interaction with VAL158, ILE166, GLY446, and LYS83. The best docking score of **2d** was

Table 2: Antileishmanial activity of synthesized compounds 2(a-j) against *Leishmania donovani*

Compound No.	% Inhibition of *Leishmania donovani*	Compound No.	% Inhibition of *Leishmania donovani*
2a	45	2f	40
2b	55	2g	50
2c	56	2h	55
2d	56	2i	55
2e	40	2j	40
Pentamidine	100		

obtained at −7.9 kcal/mole. It interacted through H-bond with ARG177, TYR401, aromatic interaction with TRP127, HIS192, TYR371 and Vander waal's interaction with CYS250, GLN321, ASP194, ARG254, GLN248, and GLU356. The best docking score of **2i** and **2j** were obtained at −8.7 and 8.8 kcal/mole, respectively. Both compounds interacted via. H-bond with HIS113, ASN123 and Vander waal's interaction with PHE414, PRO114, PHE109, TYR128, TRP127, THR125, PRO124, ARG177, and GLU409. The lowest docking score of standard drug fluconazole was found to be −7.2 kcal/mole. It exhibited H-bonding interaction with ASP194, ARG254 and Vander waal's interaction with TRP349, HIS355, LEU272, GLN257, ARG177, and TYR301.

Docking results revealed that as like to the standard drug, the ligands **2a, 2d, 2i,** and **2j** exhibit an equal number of hydrogen bonds to the target protein. On the basis of binding energy and interaction, it can be say that the ligands have a good binding effect to the target as compared to the fluconazole.

EXPERIMENTAL SECTION

Materials and methods

All chemicals and reagents were procured from Sigma Aldrich and Loba Chemie. Melting points of the products were determined on a Labcare LB-977 Digital Melting Point Apparatus and are not corrected. The IR spectra

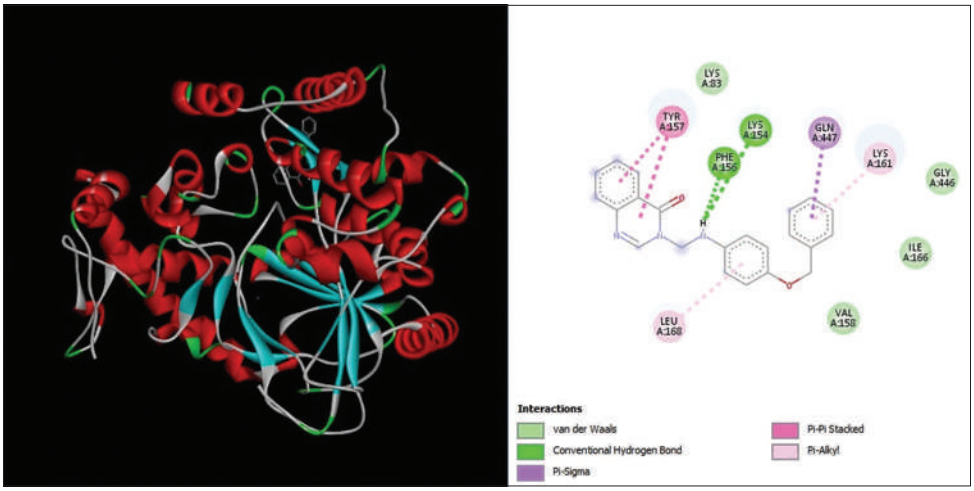


Figure 1: Docking interaction of 2a with protein 6AKZ

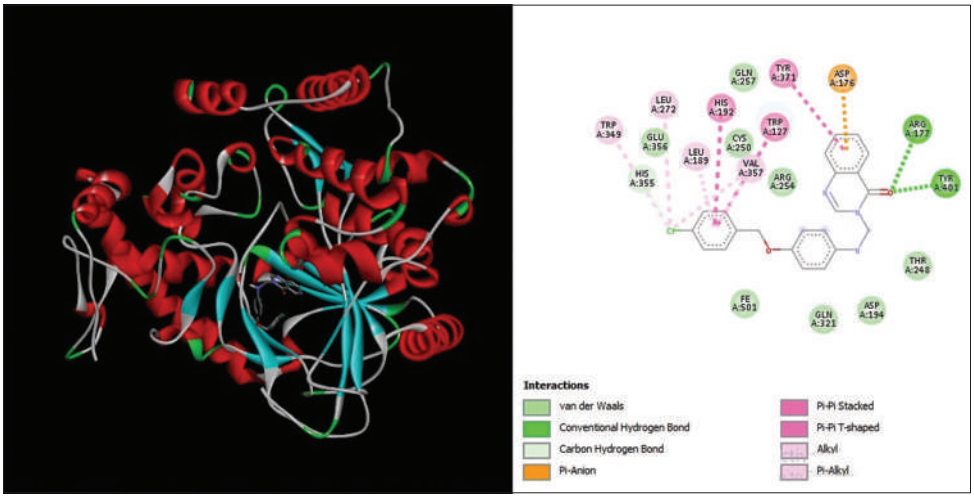


Figure 2: Docking interaction of 2d with protein 6AKZ

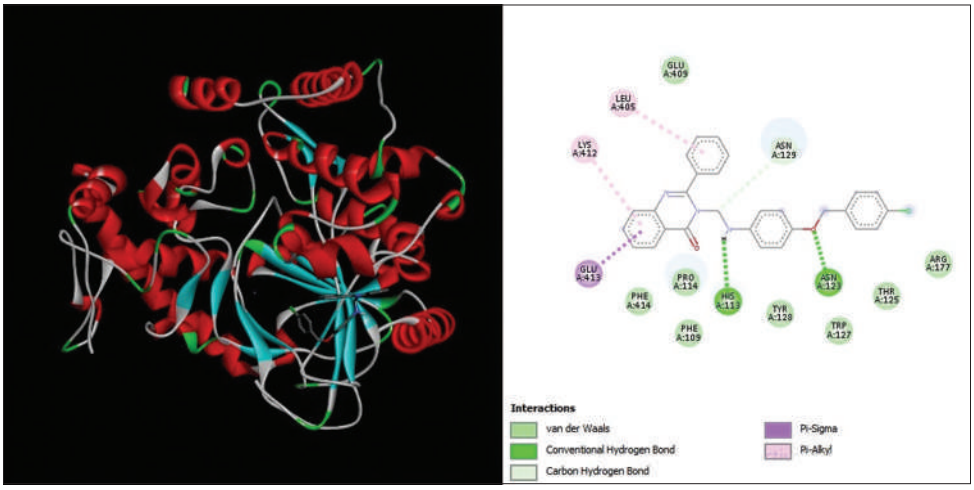


Figure 3: Docking interaction of 2i with protein 6AKZ

were recorded on a Bruker VECTOR 22 spectrometer using KBr disks. ^{1}H and ^{13}C NMR (solvent $CDCl_3$) spectra were determined on a JEOL-ECX 300 NMR spectrometer operating at 300 and 75 MHz at room temperature using tetramethylsilane as the internal standard. Mass spectral data were recorded on an Agilent 5973 organic mass spectrometer (Agilent, Santa Clara, CA). Thin-layer chromatography was performed on silica gel GF254 to

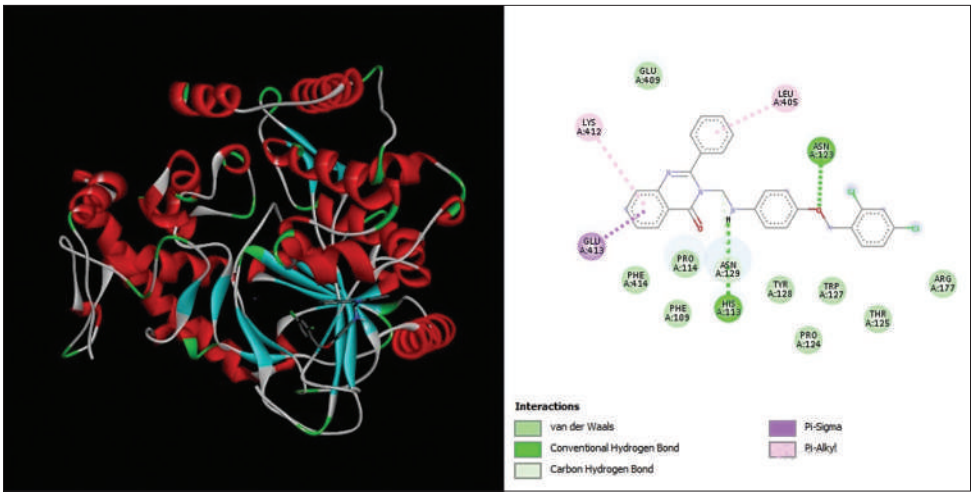


Figure 4: Docking interaction of 2j with protein 6AKZ

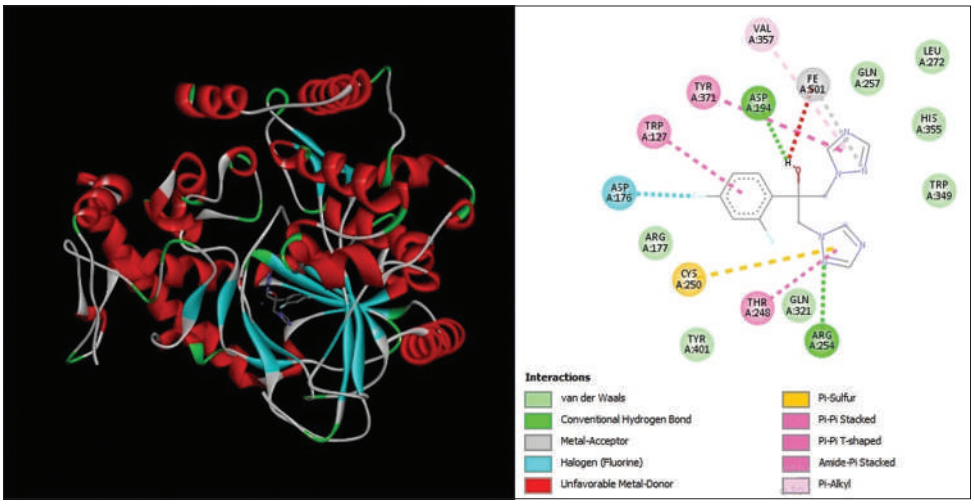


Figure 5: Docking interaction of fluconazole with protein 6AKZ

Table 3: Physical data of 3-(4-((chlorobenzyloxyphenyl) aminomethyl) quinazolin-4 (3*H*)-ones

S. No.	R^1	R^2	R^3	M. P. (°C)	Yield %	C% Found (Calc.)	H % Found (Calc.)	N% Found (Calc.)	Molecular formula
2a	H	H	H	186	67	73.87 (73.93)	5.30 (5.36)	11.70 (11.76)	$C_{22}H_{19}N_3O_2$
2b	Cl	H	H	179	78	67.35 (67.43)	4.57 (4.63)	10.67 (10.72)	$C_{22}H_{18}ClN_3O_2$
2c	H	Cl	H	180	68	67.35 (67.43)	4.56 (4.63)	10.68 (10.72)	$C_{22}H_{18}ClN_3O_2$
2d	H	H	Cl	165	77	67.40 (67.46)	4.50 (4.63)	10.67 (10.72)	$C_{22}H_{18}ClN_3O_2$
2e	Cl	H	Cl	150	66	61.90 (61.98)	3.89 (4.02)	9.82 (9.86)	$C_{22}H_{17}Cl_2N_3O_2$
2f	H	H	H	186	50	77.53 (77.58)	5.32 (5.35)	9.60 (9.69)	$C_{28}H_{23}N_3O_2$
2g	Cl	H	H	150	69	71.73 (71.87)	4.78 (4.74)	8.79 (8.90)	$C_{28}H_{22}ClN_3O_2$
2h	H	Cl	H	150	78	71.80 (71.87)	4.68 (4.74)	8.85 (8.90)	$C_{28}H_{22}ClN_3O_2$
2i	H	H	Cl	168	78	71.78 (71.97)	4.67 (4.74)	8.79 (8.90)	$C_{28}H_{22}ClN_3O_2$
2j	Cl	H	Cl	170	56	66.89 (66.94)	4.18 (4.21)	8.31 (8.36)	$C_{28}H_{21}Cl_2N_3O_2$

monitor the reaction progress. Chemical shifts are given in only one ppm, and the signals were designated as follows: s, singlet; d, doublet; m, multiplet. All reagents were of analytical reagent grade or chemically pure. All solvents were dried, deoxygenated, and redistilled before use.

General procedure for the synthesis of 3-[{4-(substitutedbenzyloxy)phenyl}aminomethyl] quinazolin-4(3*H*)-ones 2(a-e)

Quinazolin-4(3*H*)-one (**1**) (0.005 mol) was dissolved in a minimum quantity of ethanol. Formaldehyde (37%, 0.5 mL) and 4-(chlorobenzyloxy)anilines (0.005 mol) were

added with stirring vigorously. The whole contents were heated on a water bath for 2 min and left overnight at room temperature. The solid so obtained was filtered, washed with methanol, and recrystallized from chloroform, petroleum ether (60–80°C) (1:1).

3-(((4-(benzyloxy)phenyl)amino)methyl)quinazolin-4(3H)-one (2a)

FT-IR (KBr) cm^{-1}: 1692 (C=O), 1256 (-OCH_2-), 2923 (>NCH_2N<), 3345 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.23 (s, NH), 4.42 (s, 2H, >NCH_2N<), 5.15 (s, 2H, -OCH_2-), 7.12–8.19 (m, aromatic protons), 8.34 (s, >N=CHN<), ^{13}C NMR (75MHz, $CDCl_3$)δ: 65.23, 70.42, 115.24, 120.54, 126.32, 126.76, 127.17, 127.46, 127.85, 128.61, 133.49, 139.66, 147.57, 147.59, 128.48, 161.77, ES-MS 358.7 $[M+1]^+$ calculated 357.

3-(((4-((2-Chlorobenzyl)oxy)phenyl)amino)methyl) quinazolin-4(3H)-one (2b)

FT-IR (KBr) cm^{-1}: 1689 (C=O), 1309 (-OCH_2-), 2896 (>NCH_2N<), 3365 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.31 (s, NH), 4.67 (s, 2H, >NCH_2N<), 5.74 (s, 2H, -OCH_2-), 6.58–8.34 (m, aromatic protons), 8.67 (s, >N=CHN<), ^{13}C NMR (75MHz, $CDCl_3$)δ: 59.14, 68.47, 116.21, 119.26, 124.32, 125.71, 126.11, 127.46, 127.46, 128.12, 128.46, 133.45, 136.63, 145.11, 147.82, 165.73, ES-MS 393.1 $[M+2]^+$, 395.1 $[M+4]^+$ calculated 391.

3-(((4-((3-Chlorobenzyl)oxy)phenyl)amino)methyl) quinazolin-4(3H)-one (2c)

FT-IR (KBr) cm^{-1}: 1681 (C=O), 1236 (-OCH_2-), 2845 (>NCH_2N<), 3431 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.54 (s, NH), 4.93 (s, 2H, >NCH_2N<), 5.96 (s, 2H, -OCH_2-), 6.53–8.67 (m, aromatic protons), 9.01 (s, >N=CHN<), ^{13}C NMR (75MHz, $CDCl_3$)δ: 55.28, 71.22, 116.22, 118.24, 121.31, 126.76, 127.13, 127.13, 127.68, 128.96, 129.24, 135.14, 141.23, 148.56, 149.47, 159.74, ES-MS, 393.1 $[M+2]^+$, 395.1 $[M+4]^+$ calculated 391.

3-(((4-((4-chlorobenzyl)oxy)phenyl)amino)methyl) quinazolin-4(3H)-one (2d)

FT-IR (KBr) cm^{-1}: 1698 (C=O), 1223 (-OCH_2-), 2987 (>NCH_2N<), 3291 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.01 (s, NH), 4.59 (s, 2H, >NCH_2N<), 5.26 (s, 2H, -OCH_2-), 6.25–6.27 (d, 2H, J = 8.0 Hz), 6.86–6.88 (d, 2H, J= 8.0 Hz), 7.15–8.14 (m, aromatic protons), 8.27 (s, >N=CHN<), ^{13}C NMR (75MHz, $CDCl_3$)δ: 60.02, 71.43, 112.22, 116.10, 120.44, 126.33, 126.75, 127.92, 127.92, 128.05, 128.63, 129.44, 134.11, 139.63, 147.53, 147.53, 163.71, ES-MS 393.1 $[M+2]^+$, 395.1 $[M+4]^+$ calculated 391.

3-(((4-((2,4-dichlorobenzyl)oxy)phenyl)amino)methyl) quinazolin-4(3H)-one (2e)

FT-IR (KBr) cm^{-1}: 1676 (C=O), 1206 (-OCH_2-), 2909 (>NCH_2N<), 3359 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.06 (s, NH), 4.73 (s, 2H, >NCH_2N<), 5.42 (s, 2H, -OCH_2-), 6.64–8.09 (m, aromatic protons), 8.84 (s, >N=CHN<), ^{13}C NMR (75MHz, $CDCl_3$)δ: 63.22, 69.44, 111.21, 114.08, 119.11 120.44, 126.33, 126.33, 127.01, 127.40, 127.45, 128.60, 129.46, 133.44, 138.66, 147.54, 147.54, 166.75, ES-MS (m/z): 427.8 $[M+2]^+$, 429.06 $[M+4]^+$ calculated 426.

General procedure for the synthesis of 3-((4-(substitutedbenzyloxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3*H*)-ones 2(f-j)

2-Phenylquinazolin-4(3*H*)-one (**1a**) (0.005 mol) was dissolved in a minimum quantity of ethanol. Formaldehyde (37%, 0.5 mL) and 4-(chlorobenzyloxy)anilines (0.005 mol) were added with stirring vigorously. The whole contents were heated on a water bath for 2 min and left overnight at room temperature. The solid so obtained was filtered, washed with methanol, and recrystallized from chloroform, petroleum ether (60–80°C) (1:1).

3-(((4-(benzyloxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3H)-one (2f)

FT-IR (KBr) cm^{-1}: 1656 (C=O), 1260 (-OCH_2-), 2956 (>NCH_2N<), 3376 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.31 (s, NH), 4.48 (s, 2H, >NCH_2N<), 5.41 (s, 2H, -OCH_2-), 7.02–8.28 (m, aromatic protons), ^{13}C NMR (75MHz, $CDCl_3$) δ: 62.11, 70.73, 115.45, 120.07, 126.54, 126.91, 127.22, 127.74, 122.88, 128.82, 130.11, 133.22, 136.06, 146.23, 156.18, 162.76, ES-MS (m/z): 435.4 $[M+1]^+$ calculated 433.

3-(((4-((2-chlorobenzyl)oxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3H)-one (2g)

FT-IR (KBr) cm^{-1}: 1665 (C=O), 1226 (-OCH_2-), 2908 (>NCH_2N<), 3386 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 3.99 (s, NH), 4.21 (s, 2H, >NCH_2N<), 5.01 (s, 2H, -OCH_2-), 6.84–8.36 (m, aromatic protons), ^{13}C NMR (75MHz, $CDCl_3$) δ: 58.01, 66.57, 113.46, 114.04, 118.55, 120.43, 126.51, 126.90, 127.28, 127.28, 128.64, 128.89, 130.19, 133.21, 136.66, 146.03, 156.01, 159.07, ES-MS (m/z): 469.14 $[M+2]^+$, 471.14 $[M+4]^+$ calculated 467.

3-(((4-((3-chlorobenzyl)oxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3H)-one (2h)

FT-IR (KBr) cm^{-1}: 1683 (C=O), 1270 (-OCH_2-), 2960 (>NCH_2N<), 3397 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.03 (s, NH), 4.56 (s, 2H, >NCH_2N<), 5.73 (s, 2H, -OCH_2-), 7.02–8.83 (m, aromatic protons), ^{13}C NMR (75MHz, $CDCl_3$) δ: 62.17, 71.07, 115.04, 120.06, 126.55, 126.94, 127.26, 127.78, 128.62, 128.89, 130.16, 133.22, 136.63, 146.73, 156.01, 166.27, ES-MS (m/z): 469.14 $[M+2]^+$, 471.14 $[M+4]^+$ calculated 467.

3-(((4-((4-chlorobenzyl)oxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3H)-one (2i)

FT-IR (KBr) cm^{-1}: 1673 (C=O), 1265 (-OCH_2-), 2973 (>NCH_2N<), 3398 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.06 (s, NH), 4.58 (s, 2H, >NCH_2N<), 5.08 (s, 2H, -OCH_2-), 6.63–8.08 (m, aromatic protons), ^{13}C NMR (75MHz, $CDCl_3$) δ: 62.34, 70.21, 111.36, 115.71, 120.53, 126.44, 126.44, 127.11, 127.11, 128.01, 128.88, 131.37, 133.02, 135.06, 136.63, 145.98, 156.33, 162.69, ES-MS (m/z): 469.14 $[M+2]^+$, 471.14 $[M+4]^+$ calculated 467.

3-(4-((2,4-dichlorobenzyl)oxy)phenyl)amino)methyl)-2-phenylquinazolin-4(3H)-one (2j)

FT-IR (KBr) cm^{-1}: 1658 (C=O), 1258 (-OCH_2-), 2940 (>NCH_2N<), 3401 (NH), ^{1}H NMR (300MHz, $CDCl_3$)δ: 4.08 (s, NH), 4.74 (s, 2H, >NCH_2N<), 5.68 (s, 2H, -OCH_2-),

7.02–8.86 (m, aromatic protons), ^{13}C NMR (75MHz, $CDCl_3$) δ: 58.01, 69.17, 115.64, 120.17, 126.15, 126.91, 127.12, 127.12, 122.86, 128.86, 130.01, 133.62, 136.26, 146.53, 156.81, 164.46, ES-MS (m/z): 503.1 $[M+2]^+$, 505.1 $[M+4]^+$ calculated 502.

CONCLUSION

In summary, a series of 3-(4-((chlorobenzyloxyphenyl) aminomethyl)quinazolin-4(3*H*)-ones 2(a-j) was synthesized using common scaffold in this study. *In vitro* antifungal activity data revealed that the compounds **2d, 2i, and 2j** exhibited potent antifungal activity against *T. mentagrophytes*, *A. fumigatus,* and *C. albicans* with MIC values 3.12, 3.12, and 6.25 µg/mL, respectively. All synthesized compounds **2(a-j)** showed 40–56% inhibition of *L. donovani* in comparison to the standard drug pentamidine. Docking analysis revealed that the ligands **2a**, **2d**, **2i,** and **2j** displayed a good binding effect to the target as compared to the fluconazole. This is because of it exhibit the same number of H-bonds as like to standard drug. The derivatives **2a**, **2d**, **2i,** and **2j** would significantly accelerate the drug development process by reducing the risk of harmful effects on healthy tissues and organs.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Knight, C.A., Harris, D.R., Alshammari, S.O., Gugssa, A., Young, T. and Lee, C.M. Leishmaniasis: Recent epidemiological studies in the Middle East, *Front. Microbiol*., **2023**, *13*, doi: 10.3389/fmicb.2022.1052478

[2] Ali, M.A., Khamesipour, A., Rahi, A.A., Mohebali, M., Akhavan, A., Firooz, A. and Keshavarz, H.V. Epidemiological study of cutaneous leishmaniasis in some Iraqi provinces, *JOMH*, **2018**, *14*, 18–24. doi: 10.22374/1875-6859.14.4.4

[3] Mann, S., Frasca, K., Scherrer, S., Henao-Martínez, A.F., Newman, S., Ramanan, P. and Suarez, J.A. A review of leishmaniasis: Current knowledge and future directions, *Curr. Trop. Med. Rep*., **2021**, *8*, 121–132. doi: 10.1007/s40475-021-00232-7

[4] Zhang, L., Chen, Q., Li, X.Q., Wu, S.Q., Wan, J.L. and Ouyang, G.P. Synthesis and antibacterial activity of 2-substitued-(3-pyridyl)-quinazolinone derivatives, *J. Heterocycl. Chem.*, **2018**, *55*, 743–749. doi: 10.1002/jhet.3099

[5] El-Hashash, M.A., Elshahawi, M.M., Ragab, E.A. and Nagdy, S. Synthesis and antifungal activity of novel quinazolin-4(3H)-one derivatives, *Synth. Commun.*, **2015**, *45*, 2240–2250. doi: 10.1080/00397911.2015.1074697

[6] Jaiswal, R., Rastogi, N., Chaudhary, A.P., Srivastava S.K. and Kant, P, Synthesis, antifungal evaluation of 3-[{(1-aminomethyl)-5, 7-dimethyl-2-oxoindolin-3-ylidene} amino]-2-phenylquinazolin-4-(3*H*)-ones and their NLO, MESP, Global reactivity descriptor and AIM study through DFT approach, *Lett. Org. Chem.*, **2023**, *20*, 326–336. doi: 10.2174/1570178619666221004121048

[7] Wang, X., Wang, X., Zhou, B., Long, J. and Li, P. Design, synthesis, and evaluation of new 4(3H)-quinazolinone derivatives containing a pyrazole carboxamide moiety, *J. Heterocycl. Chem.*, **2021**, *58*, 2109–2116. doi: 10.1002/jhet.4334

[8] Pandey, S.K., Yadava, U., Upadhyay, A. and Sharma, M.L. Synthesis, biological evaluation and molecular docking studies of novel quinazolinones as antitubercular and antimicrobial agents, *Bioorg. Chem*., **2021**, *108*, 104611. doi: 10.1016/j.bioorg.2020.104611

[9] (a) Chaudhary, A.P., Shukla, A.K., Pandey, J. and Kant, P. Study of developments of biologically active Quinazolinones derivatives: A review, *Chem. Biol. Inter*., **2018**, *8*, 62–63. (b) Chaudhary, A.P., Shukla, A.K. and Kant, P. Synthesis, characterization and antimicrobial evaluation of N-(4-oxo-2phenyl/thiophenylquinazolin-3(4*H*)-yl)-1*H*-indole-2 or 3-carboxamide derivatives, *Chem. Biol. Interface*, **2018**, *8*, 359–372.

[10] Chaudhary, A.P. and Kant, P. Synthesis, characterization and bio evaluation of N- (substituted)-2-[4-oxo-2-phenylquinazolin-3(4H)-yl] acetohydrazide derivatives, *Am. J. PharmTech Res.*, **2018**, *8*, 294–308. doi: 10.46624/ajptr.2018.v8.i4.024

[11] Amin, N.H., El-Saadi, M.T., Abdel-Fattah, M.M., Mohammed, A.A. and Said, E.G. Development of certain aminoquinazoline scaffolds as potential multitarget anticancer agents with apoptotic and anti-proliferative effects: Design, synthesis and biological evaluation, *Bioorg. Chem*., **2023**, *135*, doi: 10.1016/j.bioorg.2023.106496

[12] El-Hashash, M.A.E.A.M., Salem, M.S. and Al-Mabrook, S.A.M. Synthesis and anticancer activity of novel quinazolinone and benzamide derivatives, *Res. Chem. Intermed*., **2018**, *44*, 2545–2559. doi: 10.1007/s11164-017-3245-4

[13] Yang, S., Lai, Q., Lai, F., Jiang, X., Zhao, C. and Xu, H. Design, synthesis, and insecticidal activities of novel 5-substituted 4, 5-dihydropyrazolo [1, 5-a] quinazoline derivatives, *Pest Manag. Sci*., **2021**, *77*, 1013–1022. doi: 10.1002/ps.6113

[14] Abdel-Aziz, A.A.M., Abou-Zeid, L.A., ElTahir, K.E.H., Ayyad, R.R., El-Sayed, M.A.A. and El-Azab, A.S. Synthesis, anti-inflammatory, analgesic, COX-1/2 inhibitory activities and molecular docking studies of substituted 2-mercapto-4 (3*H*)-quinazolinones, *Eur. J. Med. Chem*., **2016**, *121*, 410–421. doi: 10.1016/j.ejmech.2016.05.066

[15] Laleu, B., Akao, Y., Ochida, A., Duffy, S., Lucantoni, L. and Shackleford, D.M., Chen, G., Katneni, K., Chiu, F.C., White, K.L., Chen, X., Sturm, K.J. Dechering, B. Crespo, Sanz, L.M., Wang, B. S. Wittlin, S.A., Charman, V.M., Avery, Cho. N. and Kamaura, M. Discovery and structure-activity relationships of quinazolinone-2-carboxamide derivatives as novel orally efficacious antimalarials, *J. Med. Chem*., **2021**, *64*, 12582–12602. doi: 10.1021/acs.jmedchem.1c00441

[16] Prinsloo, I.F., Zuma, N.H., Aucamp, J. and N'Da, D.D. Synthesis and *in vitro* antileishmanial efficacy of novel quinazolinone derivatives, *Chem. Biol. Drug Des.*, **2021**, *97*, 383–398. doi: 10.1111/cbdd.13790

[17] Sharma, M., Chauhan, K., Shivahare, R., Vishwakarma, P., Suthar, M.K., Sharma, A., Gupta, S., Saxena, J.K., Lal, J.P., Chandra, P. Kumar, B. and Chauhan, P.M.S. Discovery of a new class of natural product-inspired quinazolinone hybrid as potent antileishmanial agents, *Med. Chem*., **2013**, *56*, 4374–4392. doi: 10.1021/jm400053v

[18] Akbari, A. and Zahedifar, M. Synthesis of quinazolin-4 (3H)-ones via a novel approach, *J. Saudi Chem. Soc*., **2023**, *27*, doi: 10.1016/j.jscs.2023.101597

[19] Mohamed, M.S., Kamel, M.M., Kassem, E.M.M., Abotaleb, N., Khedr, M. and Ahmed, M.F. Synthesis, biological evaluation and molecular docking of quinazoline-4 (1H)-one derivatives as anti-inflammatory and analgesic agents, *Acta Pol. Pharm.*, **2011**, *68*, 665–675.

[20] Chaudhary, A.P., Bharti, S.K., Kumar, S., Ved, K. and Padam, K. Study of molecular structure, chemical reactivity and first hyperpolarizability of a newly synthesized N -(4-oxo-2-phenylquinazolin-3 (4*H*)-yl)-1H-indole-2-carboxamide using spectral analysis, *J. Mol. Struct*., **2017**, *1148*, 356–363. doi: 10.1016/j.molstruc.2017.05.095

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Original Article

वाराणसी महानगर में जनसंख्या वृद्धि का गंगा नदी पर पर्यावरणीय प्रभाव : एक भौगोलिक अध्ययन

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सारांश

यह शोध पत्र वाराणसी महानगर में जनसँख्या वृद्धि का गंगा नदी पर पर्यावरणीय प्रभाव : एक भौगोलिक अध्ययन शीर्षक से सम्बन्धित है। जिसके अन्तर्गत गंगा नदी के भौगोलिक, पौराणिक व साहित्यिक महत्त्व के कारण राष्ट्रीय व अन्तर्राष्ट्रीय जनसंख्या की आकृष्टता वाराणसी महानगर की तरफ बढ़ी है की विस्तृत चर्चा की गई है। जनसंख्या के इस आकर्षण के कारण गंगा नदी भी भिन्न भिन्न रूपों में प्रभावित हुई है विशेषकर गंगा नदी पर पर्यावरणीय प्रभाव स्पष्ट रूप से परिलक्षित हो रही है महानगर में गंगा नदी के भौगोलिक, पौराणिक व साहित्यिक महत्त्व अधिक है। शोध का लक्ष्य है कि वाराणसी महानगर में गंगा नदी के उपर्युक्त महत्त्व को देखते हुए अगले कुछ दशकों में जनसँख्या की और तेजी से गतिशील होने की संभावना है जिसको ध्यान में रखते हुए यह शोध पत्र नीति नियोजको के लिए एक आधार बन सकती है।

की-वर्ड – *जनसंख्या वृद्धि, गोमुख, उपत्यिका, सीवेज ट्रीटमेंट प्लांट(एसटीपी), बीओडी(BOD)।*

प्रस्तावना

वाराणसी महानगर में बढ़ती जनसंख्या गत्यात्मकता और गंगा नदी के बीच एक गहरा सम्बन्ध है, क्योंकि महानगर का अस्तित्व ही इस नदी के किनारे बसा पड़ा है। जनसँख्या वृद्धि के कारण गंगा नदी पर दबाव बढ़ रहा है। यह प्रस्तावना जनसँख्या वृद्धि के सामाजिक आर्थिक और पर्यावर्णीय प्रभावों को गंगा नदी के सन्दर्भ में प्रस्तुत करती है, जैसे कि बढ़ती भीड़-भाड़, शहरीकरण, पर्यटन का दबाव और प्रदुषण की समस्या जो महानगर की अर्थव्यवस्था और विरासत के लिए महत्वपूर्ण है।

उद्देश्य – वाराणसी महानगर में बढ़ती जनसंख्या गत्यात्मकता के कारण पवित्र पावनी गंगा नदी को सुरक्षित एवं संरक्षित रख पाना निश्चित ही एक कठिन चुनौती है। ऐसी स्थिति में यह शोध पत्र शोध कर्ताओं व नीति नियोजकों के लिए सहायक सिद्ध हो सकती है।

भौगौलिक स्थिति

वाराणसी महानगर मध्य गंगा घाटी में गंगा नदी के बायें किनारे पर स्थित है। इसका अक्षांशीय विस्तार 25°18' उत्तरी अक्षांश और 83°01' पूर्वी देशांतर के पर स्थित है। यह महानगरीय क्षेत्र वरुणा और अस्सी नदी के बीच बसा हुआ है जो कि जलोढ़ मिट्टी से निक्षेपित भाग है। समुद्र तल से इसकी औसत उचाई 80.71 मीटर है| यह शहरी क्षेत्र लगभग 112.26 वर्ग किमी (43 वर्ग मील) में फैला हुआ है।

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जलवायु - कोप्पेन की जलवायु वर्गीकरण के अनुसार, वाराणसी नगर की जलवायु 'आर्द्र उपोष्णकटिबंधीय' (Humid Subtropical) है। इसकी एक विशेषता यह है कि यहाँ तीन ऋतुएँ पाई जाती हैं—सूखी और ठंडी सर्दियाँ धुंध के साथ, वर्षा ऋतु जिसमें वर्षा अनिश्चित होती है (कभी बहुत कम तो कभी अत्यधिक), और विशेष रूप से गर्म ग्रीष्म ऋतु। चक्रीय सूखा और बाढ़ इसकी एक अन्य विशेषता है। यहाँ का तापमान 5° से 46°C के बीच रहता है, जिसमें गर्म और ठंडी लहरें आती हैं।

तालिका-1 वाराणसी शहर की जलवायु (2011-2021)

Month	Max .Temp	Min. Temp	Av.Temp	Av.rainfall (mm)	Humidity (%)
January	22.83	9.1	15.97	17.71	73.63
February	26.35	11.48	19.10	23.28	58.44
March	31.4	16.11	23.76	17.7	43.36
April	36.95	21.77	29.36	10.35	33.32
May	39.89	25.4	32.65	15.13	37.2
June	38.34	26.21	32.28	112.92	57.25
July	32.54	25.31	28.93	285.2	77.75
August	32.86	24.72	28.79	289.6	82.18
September	32.75	24.53	28.64	250.2	82.56
October	31.44	20.6	26.02	34.81	76.63
November	29.43	14.98	22.21	7.29	73.44
December	24.74	9.94	17.34	15.38	75.68
Average	31.63	19.21	25.42	89.96	64.29

Source :Department of Geophysics, BHU,& IMD<Varanasi (2021).

गंगा नदी एक भौगोलिक परिचय – भारत की सबसे महत्वपूर्ण नदी गंगा जो भारत और बांग्लादेश में मिलकर 2510 किमी की दूरी तय करती हुई उत्तराखंड में हिमालय से लेकर बंगाल की खाड़ी से सुंदरवन तक विशाल भूभाग को सींचती है। गंगा नदी देश की प्राकृतिक सम्पदा ही नहीं जन जन की भावनात्मक आस्था का आधार भी है। इस नदी का कुल अपवाह क्षेत्र लगभग 10 लाख वर्ग किमी क्षेत्र में विस्तृत है। गंगा नदी की प्रधान शाखा भागीरथी नदी कुमाऊ हिमालय के गोमुख नमक स्थान पर गंगोत्री नामक हिमनद से निकलती है। देवप्रयाग में अलकनंदा और भागीरथी नदी का संगम होता है यहीं से यह संयुक्त धारा गंगा नदी के नाम से जाना जाता है। इस नदी के प्रमुख सहायक नदियों में यमुना,रामगंगा, करनाली, घाघरा, गंडक, कोसी है यमुना गंगा की प्रमुख सहायक है।

गंगा नदी अपनी उपत्यिकाओं(घाटियों) में भारत और बांग्लादेश के कृषि आधारित अर्थ में भारी सहयोग तो करती ही है यह अपनी सहायक नदियों सहित बहुत बड़े क्षेत्र के लिए बारहमासी स्रोत भी है। सामाजिक, साहित्यिक, सांस्कृतिक और आर्थिक दृष्टि से अत्यंत महत्वपूर्ण गंगा का यह मैदान अपनी घनी जनसंख्या के कारण भी जाना जाता है।

गंगा नदी भारत की सबसे महत्वपूर्ण नदियों में से एक है। यह पाँच राज्यों और कई बड़े-छोटे शहरों से होकर बहती है। वाराणसी में गंगा का भौगोलिक और पौराणिक महत्व अतुलनीय है। भौगोलिक रूप से, यह "उत्तर वाहिनी" है, यानी दक्षिण से उत्तर की ओर बहती है, जो एक शुभ माना जाता है। पौराणिक रूप से, यह एक पवित्र देवी है, जिसके जल में डुबकी लगाने से पाप धुल जाते हैं और मोक्ष की प्राप्ति होती है। शहर के 84 घाटों का भी गहरा धार्मिक महत्व है, जो जीवन-मरण के चक्र से मुक्ति के द्वार माने जाते हैं। वाराणसी गंगा नदी के किनारे बसे प्रमुख शहरों में से एक है और सबसे महत्वपूर्ण धार्मिक एवं पर्यटन शहरों में से एक है।

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अनुसंधान पद्धति – प्रस्तुत शोध पत्र **"वाराणसी महानगर में जनसंख्या वृद्धि का गंगा नदी पर पर्यावरणीय प्रभाव : एक भौगोलिक अध्ययन"** के सम्बन्ध में विभिन्न माध्यमों से लिए गए अनुसंधानों एवं इस प्रकार के विषय वास्तु को लक्ष्य में रखकर किये गए अध्ययनों का विवेचन किया गया है। शोध पत्र के लिए आवश्यक तथ्यों का अभिकेन्द्र भारतीय जनगणना द्वारा प्रदत्त आंकड़े रहे हैं। इस सन्दर्भ में आंकड़ों की प्राप्ति निम्न विधियों द्वारा किया गया है -

(अ)प्राथमिक स्रोत - इस विधि में आंकड़ों का संकलन प्रश्नावली, आपसी बातचीत एवं स्वयं आकलन द्वारा किया गया है।

(ब) द्वितीयक स्रोत - इस विधि में आंकड़ों को विभिन्न सरकारी एवं गैर सरकारी अभिलेखों, जनगणना पुस्तिका, पुराने अभिलेख एवं ग्रन्थ, पुस्तकों संग्रहालयों आदि से प्राप्त किया गया है।

वाराणसी महानगर में जनसँख्या वृद्धि – वाराणसी महानगर की जनसंख्या वृद्धि दर 17.32% (2001-2011) थी, और 2025 में अनुमानित जनसंख्या 20.8 लाख है। 2011 की जनगणना में वाराणसी शहर की जनसंख्या 1,198,491 और शहरी/महानगरीय जनसंख्या 1,423,711 थी।

मुख्य आँकड़े

- 2025 का अनुमानित जनसंख्या: 2,080,000 (महानगर)
- 2011 की जनगणना (शहर): 1,198,491
- 2011 की जनगणना (शहरी/महानगरीय): 1,423,711
- 2001-2011 जनसंख्या वृद्धि दर (जिला): 17.32%
- 2011 में शहरी जनसंख्या: 43.44% (वाराणसी जिले की)

जनसंख्या वृद्धि के कारण

ग्रामीण आबादी का शहरीकरण – बेहतर शिक्षा, स्वास्थ्य सेवाओं, रोजगार और परिवहन जैसे अवसरों की तलाश में ग्रामीण क्षेत्रों से शहरों की ओर लोगों का पलायन हो रहा है।

आप्रवासन - अन्य स्थानों से लोगों का आना।

धार्मिक महत्व – वाराणसी गंगा नदी के किनारे स्थित एक पवित्र शहर है और गंगा को हिन्दू धर्म में महत्वपूर्ण माना जाता है। शहर के घाटों पर स्नान व पूजा पाठ के लिए हार साल लाखो लोग आते हैं।

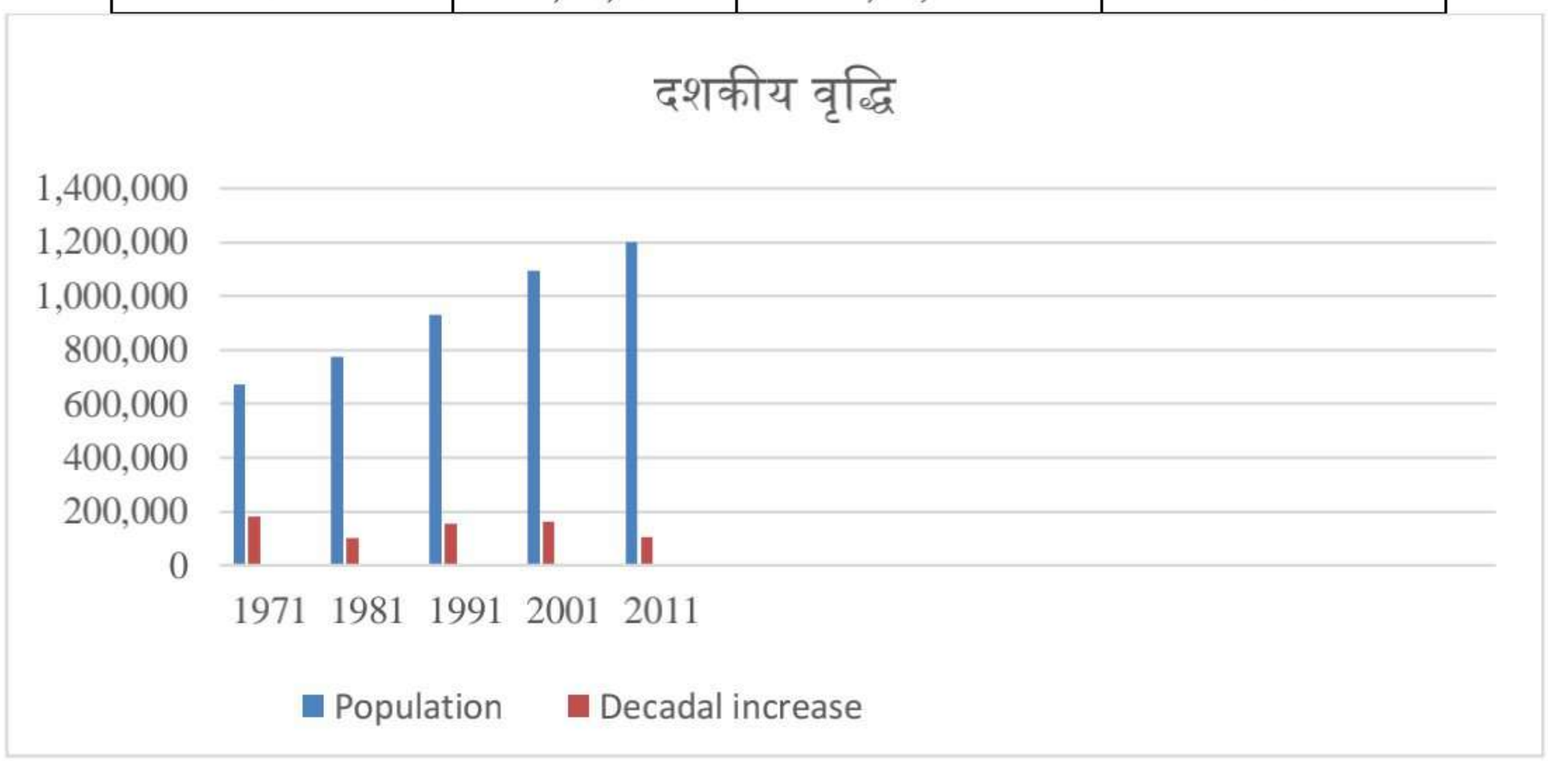
जनसंख्या वृद्धि से जुड़ी चिंताएँ -

अनियोजित शहरी विस्तार - यह एक बड़ी चुनौती है जो कई सामाजिक और पर्यावरणीय समस्याओं को जन्म दे रही है।

भीड़भाड़ - बढ़ती आबादी से शहर के बुनियादी ढांचे पर दबाव बढ़ रहा है।

तालिका – 2 वाराणसी शहर की दशकीय जनसंख्या वृद्धि प्रवृत्ति

Census Year	Population	Decadal increase	Growth Rate (%)
1971	6,71,934	1,82,070	37%
1981	7,73,865	1,01,931	15%
1991	9,29,270	1,55,405	20%
2001	10,91,918	1,62,648	18%
2011	11,98,492	1,06,574	10%



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अनियंत्रित बढ़ती जनसंख्या वाराणसी महानगर के सामाजिक, आर्थिक और पर्यावरणीय समस्यायों को जन्म दे रही है। वाराणसी में बढ़ती जनसंख्या और जल प्रदूषण का गहरा संबंध है, जहाँ जनसंख्या वृद्धि से सीवेज और कचरे का भारी बोझ बढ़ता है, जिससे भूजल और गंगा नदी प्रदूषित होती है। यह बढ़ती आबादी के लिए स्वच्छ जल की कमी, जलजनित बीमारियों और पुराने जल आपूर्ति सिस्टम पर अत्यधिक दबाव जैसी समस्याएँ पैदा करती है, जिसे पुराने कुंडों पर अतिक्रमण और जल-जमाव की समस्याएँ और बढ़ाती हैं।

अनियंत्रित जनसंख्या वृद्धि का गंगा नदी पर पर्यावरणीय प्रभाव –

वाराणसी में गंगा नदी पर प्रदूषण का मुख्य प्रभाव औद्योगिक और घरेलू कचरा, सीवेज और धार्मिक क्रियाओं से हो रहा है, जिससे पानी की गुणवत्ता खराब हो रही है। इससे पर्यावरण को कई तरह से नुकसान हो रहा है, जैसे कि जलजनित बीमारियाँ, मछलियों की संख्या में कमी और स्थानीय पारिस्थितिकी तंत्र पर नकारात्मक असर। इसके अतिरिक्त, अत्यधिक बारिश या बाढ़ के कारण नदी का जलस्तर बढ़ सकता है, जिससे बाढ़ का खतरा पैदा होता है और रिहायशी इलाकों में पानी घुस जाता है।

तालिका – 3 वाराणसी में गंगा नदी की जल गुणवत्ता -

वर्ष	स्टेशन	पीएच		बीओडी मिलीग्राम/लीटर	
		न्यूनतम	अधिकतम	न्यूनतम	अधिकतम
जल गुणवत्ता मानदंड		6.5-8.5		<3 मिलीग्राम/लीटर	
2010	अस्सी घाट	7.3	7.7	3.4	4.2
2010	मालवीय ब्रिज	7.8	8.8	4.2	10.8
कुल		15.1	16.5	7.6	15.0
2011	अस्सी घाट	7.5	7.8	3.7	4.2
2011	मालवीय ब्रिज	7.9	8.1	5.2	9.6
कुल		15.4	15.9	8.9	13.8
2012	अस्सी घाट	7.7	8.5	2.8	3.5
2012	मालवीय ब्रिज	7.5	8.5	5.1	8.5
कुल		15.2	17.0	7.9	12.0
2013	अस्सी घाट	7.6	8.4	2.9	3.2
2013	मालवीय ब्रिज	7.7	8.4	3.3	5.1
कुल		15.3	16.8	6.2	8.3
2014	अस्सी घाट	7.2	8.0	2.3	3.8
2014	मालवीय ब्रिज	8.0	8.4	2.4	3.3
कुल		15.2	16.4	4.7	7.1
2015	अस्सी घाट	7.3	8.3	2.8	3.5
2015	मालवीय ब्रिज	7.9	8.5	3.1	4.3
कुल		15.2	16.8	5.9	7.8
2016	अस्सी घाट	7.4	8.5	2.8	3.5
2016	मालवीय ब्रिज	7.3	8.6	4.2	6.8
कुल		14.7	17.1	7.0	10.3

स्रोत- सेंट्रल पोल2018 (लेखक द्वारा तैयार)

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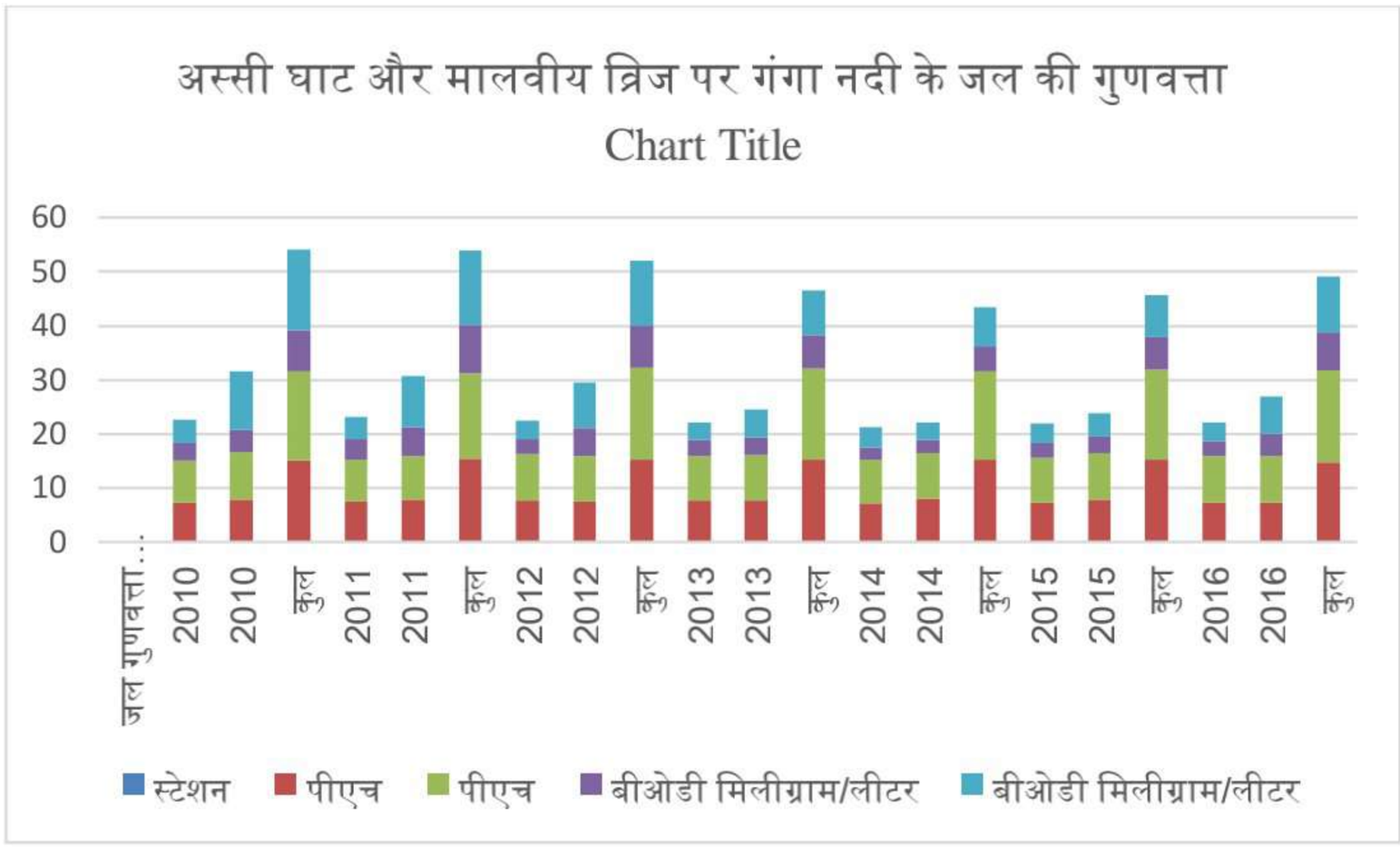

प्रमुख पर्यावरणीय प्रभाव : निम्नलिखित प्रभाव अग्रलिखित है -

1- जल की गुणवत्ता में गिरावट:

शहर से निकलने वाला औद्योगिक, नगरपालिका और अस्पताल अपशिष्ट सीधे नदी में छोड़ा जाता है। कचरा संग्रहण व्यवस्था की कमी के कारण अधिकांश कचरा खुले नालों से होकर गंगा में पहुँचता है।

2- जैविक और भौतिक मापदंडों में गिरावट:

मानवजनित निर्वहन से नदी के भौतिक और जैविक मापदंडों में महत्वपूर्ण गिरावट आई है।

3- प्रदूषणकारी और खतरनाक पदार्थ:

इलाहाबाद, वाराणसी, और पटना जैसे शहरों से निकलने वाले अपशिष्ट जल का नदी में बहाव एक बड़ी समस्या है। वाराणसी में उत्पन्न होने वाला 33% गंदा पानी सीधे गंगा में मिल रहा है। अस्सी नदी (अस्सी नाला) को गंगा प्रदूषण का सबसे बड़ा स्रोत माना जाता है।

4- अन्य प्रभाव:

नदियों के किनारे हरे शैवाल (algal blooms) की समस्या देखी जा रही है, जो पोषक तत्वों की अधिकता के कारण होता है। नदी का पानी प्रदूषित होने के कारण लोग उसमें स्नान करने से कतराते हैं। धार्मिक अनुष्ठान, जैसे कि शवों के अवशेषों का नदी में विसर्जन भी प्रदूषण का एक कारण है।

5- अतिरिक्त दबाव:

जनसंख्या में वृद्धि, शहरीकरण और मानवीय गतिविधियों के कारण नदी और उसके आसपास के पारिस्थितिक तंत्र पर दबाव बढ़ रहा है। बढ़ते प्रदूषण से जलजनित बीमारियाँ फैलती हैं, जिससे स्थानीय समुदाय के स्वास्थ्य पर बुरा असर पड़ता है। मछली पकड़ने वालों की आजीविका भी प्रभावित होती है, क्योंकि मछली की संख्या में कमी आ रही है। प्रदूषण के कारण पर्यटकों का आना भी कम हो रहा है, जिससे स्थानीय अर्थव्यवस्था पर भी नकारात्मक प्रभाव पड़ रहा है।

6-बाढ़ का खतरा:

अत्यधिक बारिश और बाढ़ के कारण गंगा नदी का जलस्तर खतरनाक स्तर तक पहुँच रहा है। बाढ़ के कारण वाराणसी के सभी घाट पूरी तरह से जलमग्न हो गए हैं। जलस्तर बढ़ने से कई रिहायशी इलाकों में पानी घुस रहा है, जिससे लोगों को परेशानी हो रही है और आवागमन बाधित हो रहा है।

गंगा में प्रदूषण के 2006 के एक मापन से पता चला है कि पिछले 12 वर्षों में नदी के जल की निगरानी से पता चला है कि वाराणसी में नदी के सबसे प्रदूषित हिस्से में प्रति 100 मिलीलीटर में 100,000,000 एमपीएन तक फेकल कोलीफॉर्म की

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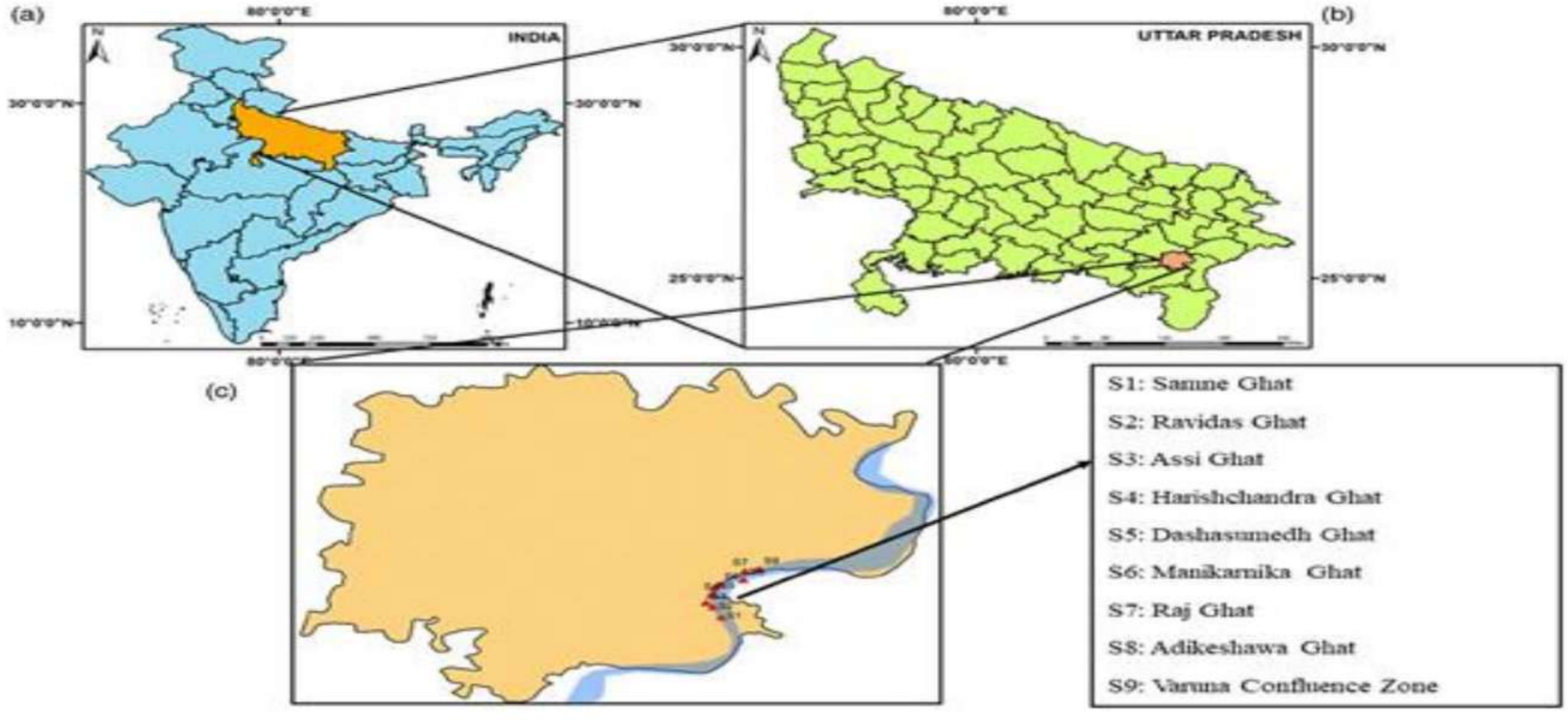
मात्रा और जैविक ऑक्सीजन की माँग(BOD) का स्तर औसतन 40 मिलीग्राम/लीटर से अधिक था। तीव्र जठरांत्र रोगों सहित जल जनित रोगों की कुल दर लगभग 66% अनुमानित की गई थी।

जल गुणवत्ता की विस्तृत जाँच के लिए, गंगा नदी के शहरी स्थलों पर कुल नौ नमूना बिंदु (S1, S2, S3, S4, S5, S6, S7, S8 और S9 के रूप में नामित) निर्धारित किए गए थे। नमूना लेने के स्थानों का चयन नालों की उपस्थिति, प्रदूषण स्रोतों, जनसंख्या घनत्व, संभावित मानवजनित गतिविधि और क्षेत्र के सामाजिक-आर्थिक महत्व के आधार पर किया गया था।



जल जनित बिमारियां -

2006 और 2007 में गंगा के पानी के विश्लेषण से जल जनित बीमारियों और नहाने, कपड़े धोने, कपड़े धोने, खाने, बर्तन साफ करने और दाँत ब्रश करने के लिए नदी के उपयोग के बीच महत्वपूर्ण संबंध सामने आए। गंगा के पानी को पेचिश, हैजा, हेपेटाइटिस, और गंभीर दस्त से जोड़ा गया है, जो भारत में बच्चों की मृत्यु के प्रमुख कारणों में से एक है। गर्मी और मानसून के दौरान, अस्पताल के वार्ड जलजनित बीमारियों के इलाज की ज़रूरत वाले बच्चों से भरे रहते हैं - लेकिन वाराणसी शिव प्रसाद गुप्ता अस्पताल के बाल रोग विशेषज्ञ एससी सिंह के अनुसार , उनके माता-पिता शायद ही कभी बताते हैं कि वे नदी में तैर रहे थे। उनका कहना है कि ऐसा लगता है कि उन्होंने इस संबंध को नहीं समझा।

सीवेज और अपशिष्ट का बढ़ता बोझ -

बढ़ती आबादी के कारण घरों और उद्योगों से निकलने वाले सीवेज और कचरे का प्रबंधन एक बड़ी चुनौती है। ये अपशिष्ट पदार्थ अक्सर बिना उपचार के नदी में या जल-भराव वाले निचले इलाकों में छोड़े जाते हैं, जिससे भूजल और नदी प्रदूषित होती है।

अपुराणी जल आपूर्ति व्यवस्था -

शहर की जल आपूर्ति प्रणाली 100 साल पुरानी है और इसे लगभग 2 लाख की आबादी के लिए डिज़ाइन किया गया था। आज की बढ़ती आबादी की मांग को पूरा करने के लिए इसकी क्षमता पर अत्यधिक दबाव है।

नमामि गंगे कार्यक्रम

10 जुलाई 2014 को संसद में पेश किए गए बजट में , केंद्रीय वित्त मंत्री अरुण जेटली ने "नमामि गंगे" (जिसका अर्थ है 'गंगा नदी को नमन') नामक एक एकीकृत गंगा विकास परियोजना की घोषणा की और इस उद्देश्य के लिए ₹2,037 करोड़ आवंटित किए। उद्देश्य प्रदूषण का प्रभावी उन्मूलन, संरक्षण और गंगा का कायाकल्प करना था। यह परियोजना 8 राज्यों को कवर करती है। पेयजल आपूर्ति और स्वच्छता मंत्रालय ने ₹1,700 करोड़ (केंद्रीय हिस्सा) की लागत से गंगा के किनारे 1,674 ग्राम पंचायतों को खुले में शौच से मुक्त बनाने का प्रस्ताव रखा। नदी की सफाई के विभिन्न प्रयासों पर जुलाई 2016 तक अनुमानित ₹2,958 करोड़ (US $460 मिलियन) खर्च किए गए थे। कार्यक्रम के एक भाग के रूप में, भारत सरकार ने गंगा के आसपास की 48 औद्योगिक इकाइयों को बंद करने का आदेश दिया। इस कार्यक्रम का बजट परिव्यय अगले पाँच वर्षों के लिए ₹20,000 करोड़ था, जो पिछले 30 वर्षों के व्यय (भारत सरकार ने 1985 से इस

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कार्य पर लगभग ₹4,000 करोड़ खर्च किए हैं) की तुलना में पाँच गुना उल्लेखनीय वृद्धि दर्शाता है। केंद्र सरकार अब इस कार्यक्रम के अंतर्गत विभिन्न परियोजनाओं के लिए 100% वित्तपोषण वहन करेगी। पिछली गंगा कार्य योजनाओं के असंतोषजनक परिणामों से सीखते हुए, केंद्र सरकार कम से कम 10 वर्षों के लिए संचालन और रखरखाव परिसंपत्तियाँ प्रदान करने और प्रदूषण के प्रमुख बिंदुओं से निपटने के लिए सार्वजनिक-निजी भागीदारी (पीपीपी) या विशेष प्रयोजन वाहन (एसपीवी) दृष्टिकोण अपनाने की योजना बना रही है। "नमामि गंगे" मुख्य रूप से खुले नालों से बहने वाले अपशिष्ट जल को रोकने, मोड़ने और उपचारित करने के माध्यम से प्रदूषण निवारण उपायों पर केंद्रित होगा। इस कार्यक्रम में जैव-उपचार, उपयुक्त इन-सीटू उपचार, नवीन तकनीकों, सीवेज उपचार संयंत्रों (एसटीपी) और अपशिष्ट जल उपचार संयंत्रों (ईटीपी) का उपयोग किया जाएगा। इसका उद्देश्य मौजूदा एसटीपी का पुनर्वास और संवर्धन करना तथा नदी के निकास बिंदुओं पर प्रदूषण को रोकने और सीवेज के अंतर्वाह को रोकने के लिए तत्काल अल्पकालिक उपायों को लागू करना है। महत्वपूर्ण बात यह है कि यह दृष्टिकोण सामाजिक-आर्थिक लाभों के लिए उल्लेखनीय है, जिसमें रोजगार सृजन, जीवन की बेहतर गुणवत्ता और नदी पर निर्भर विशाल आबादी के लिए स्वास्थ्य लाभ शामिल हैं। नमामि गंगे कार्यक्रम के मुख्य स्तंभ हैं:

1. सीवरेज उपचार अवसंरचना
2. नदी-तट विकास
3. नदी-सतह की सफाई
4. जैव विविधता
5. वनीकरण
6. जन जागरण
7. औद्योगिक अपशिष्ट निगरानी
8. गंगा ग्राम

भविष्य के लिए व्यावहारिक समाधान

पहले बताई गई रणनीतियों के अलावा, गंगा नदी बेसिन के प्रबंधन के लिए एक अधिक टिकाऊ दृष्टिकोण में निम्नलिखित उपाय शामिल हो सकते हैं:

- **न्यूनतम पारिस्थितिक प्रवाह का रखरखाव** : नदी के प्राकृतिक स्व-सफाई क्षमता को बनाए रखने के लिए उसके पारिस्थितिक प्रवाह का कम से कम 51% बनाए रखना सुनिश्चित करना। जलविद्युत परियोजनाओं को इस आवश्यकता को पूरा करने के लिए पुनः डिज़ाइन किया जाना चाहिए, और अनुपालन न करने पर कठोर प्रवर्तन और दंड का प्रावधान किया जाना चाहिए।
- **टिकाऊ कृषि पद्धतियाँ** : प्रदूषण और कृषि अपवाह को कम करने के लिए कृषि संरक्षण, फसल चक्र और जैविक उर्वरकों के उपयोग जैसी प्रथाओं को प्रोत्साहित करना।
- **उद्योगों से निकलने वाले अपशिष्ट जल का पुनर्चक्रण** : अपशिष्ट जल का पुनर्चक्रण, संवेदनशील पारिस्थितिक तंत्रों से जल के विचलन को कम करता है, प्रदूषण को कम करता है और खेती के लिए आवश्यक पोषक तत्व प्रदान करता है। कृषि जैसे गैर-पेय प्रयोजनों के लिए आंशिक रूप से उपचारित जल के पुन: उपयोग को बढ़ावा देना।
- **नवीन स्वच्छता सुविधाएँ** : नदी के किनारे खुले में शौच को कम करने के लिए बायोडाइजेस्टर शौचालयों का कार्यान्वयन। इन शौचालयों में अपशिष्ट का अवायवीय प्रसंस्करण, नवीकरणीय ऊर्जा स्रोत के रूप में मीथेन का उत्पादन और खाद के रूप में इस्तेमाल होने वाला कीचड़ उत्पन्न करना शामिल है।
- **सीवर अवसंरचना को सुदृढ़ करना** : मौजूदा सीवेज उपचार संयंत्रों को बढ़ाने और बनाए रखने के लिए सौर ऊर्जा का उपयोग।
- **जागरूकता और हितधारक भागीदारी** : प्राथमिक स्कूली शिक्षा के स्तर पर नदी संरक्षण पर शिक्षा का विस्तार करना और गैर सरकारी संगठनों, स्थानीय समुदायों और सरकारी निकायों सहित हितधारक सहयोग को बढ़ाना। लॉकडाउन के दौरान कम हुई मानवीय गतिविधि के सकारात्मक प्रभाव का एक महत्वपूर्ण उदाहरण देखा गया, जब जैव रासायनिक ऑक्सीजन मांग और रासायनिक ऑक्सीजन मांग सांद्रता कम हो गई, साथ ही समग्र जल प्रदूषण 50% तक गिर गया।

निषकर्ष

वाराणसी महानगर की पहचान पिछले कुछ वर्षो में राष्ट्रीय व अन्तर्राष्ट्रीय स्तर पर तेजी से बढ़ा है। प्रधानमंत्री का संसदीय क्षेत्र होने के कारण यह महानगर अपने विकास के चरम को प्राप्त कर रहा है| साथ ही साथ वाराणसी महानगर आमजन के लिए आध्यात्मिक आस्था का केन्द्र भी है। इन सब प्रभाव के कारण वाराणसी महानगर में जनसंख्या का तेजी से सकेन्द्रण हुआ है। जनसंख्या आधिक्य के कारण

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भिन्न-भिन्न प्रकार के प्रदूषक तत्व भी जनित हो रहे है। प्रदूषक तत्वों में जल प्रदूषक भी शामिल हैं जिससे जन-जन की आस्था का प्रतीक गंगा नदी भी प्रभावित हुई हुई है। आवश्यकता है गंगा नदी को सुरक्षित व संरक्षित करने की, जिससे कि हम अपने देश के जीवन आधार को बचा सकें। सरकारी व निजी स्तर पर कुछ प्रयाश किये जा रहे हैं लेकिन ये नाकाफी है। वाराणसी महानगर में आने वाले कुछ वर्षों के साथ जनसंख्या में और वृद्धि होगी जिससे गंगा नदी के और प्रभावित होने की संभावना है। अब आवश्यकता है कि जन जागरूकता कार्यक्रमों में तेजी लाया जाय और उचित नीति नियोजन बनाकर उसे क्रियान्वित किया जाय।

सन्दर्भ ग्रन्थ

1. तिवारी, राम कुमार(2015), जनसँख्या भूगोल, प्रवालिका पब्लिकेशन्स इलाहाबाद ISBN : 978-93-84292-05-08
2. कुमारी, प्रभा "जनसंख्या विस्फोट और पर्यावरण प्रदूषण" प्रकाशक: वाणी प्रकाशन ISBN-10: 8181438582, ISBN-13: 978-8181438584
3. सिंह, सविन्द्र(2014), पर्यावरण भूगोल, प्रयाग पुस्तक भवन इलाहाबाद ISBN : 81-86539-54-9
4. Singh Rana P.B. 2018. Urbanisation in Varanasi and interfacing Historic Urban
5. Landscapes; a special lecture in the National Seminar on "Urbanization in Indian
6. History": 5–6 January 2018. C.P.R. Institute of Indological Research, # 1, Eldams Road,
7. Alwarpet, Chennai, TN 600018. <32-pp: 14,660 words, 13 figs.> Strictly © the aut
8. चतुर्वेदी, ए (2017). "भारत की सीवेज समस्या और समाधान" स्टैनफोर्ड सोशल इनोवेशन रिव्यू. पृ. 3– 4.
9. श्रीनिवास, आर.; सिंह, अजीत प्रताप; शंकर, दिव्यांशु (अप्रैल 2020)। "सतत विकास की दिशा में प्रभावी नीतिगत सिफारिशों के लिए गंगा नदी बेसिन से संबंधित खतरों और चुनौतियों को समझना"। पर्यावरण, विकास और स्थिरता। 22(4):3655–3690.doi:10.1007/s10668-019-00361-0।
10. भारतीय स्थानिक विज्ञान जर्नल, वसंत अंक, 2021:12(1) पृष्ठ 47 - 59
11. खतरे में गंगा का अस्तित्व – ASPX पत्रिका
12. भागीरथी और गंगा – स्पिरिचुअल इंडिया
13. चक्रपाणि और सैनी 2009 ; एनएमसीजी 2019

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शिक्षा के क्षेत्र में क्रान्ति एवं इंटरनेट की भूमिका : एक शैक्षिक विमर्श

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सारांश : *आज ऑनलाइन शिक्षा के क्षेत्र में आधुनिक शिक्षण मशीनों मोबाइल, स्मार्ट फोन, लैपटॉप, टेबलेट, रेडियो, टेपरिकॉर्डर, ग्रामोफोन, टेलीविजन, प्रोजेक्टर, भाषा प्रायोगशाला आदि द्वारा शिक्षण आदि के प्रयोगों ने शिक्षा प्रक्रिया का मशीनीकरण कर दिया है। आज मशीनों के प्रयोग से शिक्षक अपने विद्यार्थियों को आसानी से अपने ज्ञान कौशल से लाभान्वित करा सकता है। शिक्षा के क्षेत्र में शिक्षण मशीनों का उपयोग आज तेजी से बढ़ता जा रहा है। आज कल इंटरनेट का प्रयोग न केवल ई–शिक्षा में ही किया जा रहा हैं, बल्कि ऑनलाइन फॉर्म भरने, नौकरी के लिए आवेदन करने और पुस्तके पढ़ने में भी किया जा रहा हैं। आज विद्यार्थी शिक्षा के सभी क्षेत्रों में इंटरनेट का उपयोग कर रहे हैं।*

मुख्य शब्द : *शिक्षा, सूचना और संचार प्रौद्योगिकी, क्रान्तिकारी परिवर्तन, संयुक्त राष्ट्र विकास कार्यक्रम, शैक्षिक अनुसंधान नेटवर्क आदि।*

प्रस्तावना : प्राचीनकाल में मौखिक एवं कंठस्थ रूप ग्रहण की जाती थी, जो शिक्षा क्षेत्र **पहली क्रान्ति** थी। समय के साथ शिक्षा का स्वरूप और इसके तौर तरीकों में बदलाव आया। इसके बाद में धीरे–धीरे शिक्षा उपकरणों के रूप में लिखित शब्दों का उपयोग होने लगा। यह **दूसरी क्रान्ति** रही। जिसके फलस्वरूप स्कूलों में मौखिक शिक्षा के साथ लिखित शिक्षा ने भी स्थान ले लिया। इसके फलस्वरूप शिक्षा को अध्ययन हेतु घरो की दीवारों पेड़ो के पत्तों, गुफाओं की दीवारों पर संकेतो के द्वारा लिखित रूप में दर्शाया जाने लगा था। **तीसरी क्रान्ति** मुद्रण के अविष्कार के साथ आयी तथा पुस्तकें उपलब्ध होने लगी, यह तीसरी क्रांति रही। इलेक्ट्रॉनिक्स तकनीकी क्षेत्र में आये विकासशील परिवर्तन चौथी क्रान्ति के सूचक रहे। इसके बाद रेडियो तथा टेलीविजन आदि का प्रयोग शिक्षा के क्षेत्र में होने लगा। कम्प्यूटर, लैपटॉप, टेबलेट, मोबाइल, स्मार्ट फोन एवं सीडी–डीवीडी आदि के आने से संचार के क्षेत्र में विकास हुआ जिससे कि ईमेल, डिजिटल वीडियो, ई–बुक्स, ई–शिक्षा, ऑनलाइन शिक्षा और इंटरनेट के माध्यम से शिक्षा के क्षेत्र इन यंत्रों ने नई क्रान्ति का उदय किया। इन साधनों ने शिक्षा के क्षेत्र में पुरानी अवधारणाओं में आधुनिक सन्दर्भ के साथ अभूतपूर्व क्रान्तिकारी परिवर्तन करके उन्हें एक नया स्वरूप प्रदान किया है।[1]

इन सब ने मिलकर **पाँचवीं क्रान्ति** को जन्म देगी जिसके परिणामस्वरूप संसार की लगभग सारी शिक्षा व्यवस्था का ब्यौरा अर्थात शिक्षा दर्शन, शिक्षा की विषय–वस्तु, पाठ्यक्रम शोध–पत्र, पत्र–पत्रिकाएँ, ई–बुक्स, ई–लाईब्रेरी आदि एक डिब्बे में बन्द हो सकेगा और संसार का कोई भी व्यक्ति अथवा विद्यार्थी कहीं भी किसी भी एक कोने में बैठकर ऑनलाइन अध्ययन के द्वारा बड़ी से बड़ी उच्च शिक्षा की डिग्री प्राप्त कर सकेगा। उस समय ऐसी बातों को लोग मजाक समझते थे और यकीन नहीं करते थे, लेकिन आज सूचना और संचार प्रौद्योगिकी ने यह कर दिया हैं।

आज के विद्यार्थी कालेज और विश्वविद्यालयों में शिक्षकों से केवल एक तिहाई शिक्षा अपने सहपाठी समूह से और बाकी स्व–अध्ययन के द्वारा सीखते हैं। सिर्फ विश्वविद्यालय ही सीखने के स्रोत नहीं रहे हैं, न ही वे सभी को आजीवन शिक्षा के आधार पर उच्च शिक्षा, तकनीकी दक्षता और व्यावसायिक प्रशिक्षण प्रदान करने की जिम्मेदारी उठा सकते हैं। आज मल्टीमीडिया और इंटरनेट के प्रयोग ने एक नए युग की शुरुआत कर दी है, जिसने विद्यार्थियों और शिक्षकों में उम्मीदे जगा दी हैं।[2]

नई तकनीक मशीने एवं इंटरनेट सीखने वालों को लचीलापन प्रदान करती हैं। चूँकि ये सीखने वालों की सभी इन्द्रियों को एक साथ परस्पर संबंधित करती हैं, इसलिए सीखना दिलचस्प हो जाता है। इन मशीनी इकाइयों द्वारा शिक्षा को मनोरंजन के साथ मिश्रित करना भी आसान हो जाता है। इस प्रकार यह शिक्षा आधारित मनोरंजन बन जाता है। ये काफी प्रोत्साहन देने वाले होते हैं और सीखने वालों को **'शक्ति'** और **'सत्ता'** प्रदान करते है। इस प्रकार सूचना के इस युग में शिक्षा और सीख के लिए नई तकनीकों का अधिक दिलचस्प और कारगर ढंग से प्रयोग करना संभव हो गया हैं।

इंटरनेट दैनिक जीवन में परिवर्तन का माध्यम बन गया है। **रिचर हुकर** ने चेतावनी दी थी कि परिवर्तन असुविधाजनक ही होता है। इंटरनेट एक सूचना का बहुत बड़ा भण्डार है जिसने संसार की जानकारियों को एक जगह उपलब्ध करा कर एक अदभुत कार्य किया है। यह सभी विषयों पर सूचना उपलब्ध कराता है और संसार भर में कहीं भी इसे एक्सेस किया जा सकता है। इंटरनेट ने आज विद्यार्थियों को अपनी मर्जी, अपने समय और अपने स्थान के अनुसार अपने को आगे बढ़ाने का विकल्प दिया है। विद्यार्थी पाठ्य सामग्री तक पलक झपकते पहुँच जाते हैं। इसमें विद्यार्थियों की सीधी पहुँच होती हैं और वे अपनी मर्जी, अपने समय और अपने स्थान के अनुसार अपने अध्ययन को आगे बढ़ाने का विकल्प दिया है। विद्यार्थी पाठ्य सामग्री तक पलक झपकते पहुँच जाते हैं। इसमें विद्यार्थियों की सीधी पहुँच होती हैं और वे अध्ययन तथा सीखने के बजाये खोज करने से सीखते हैं।[3] इस प्रकार सीखने की प्रक्रिया अपेक्षाकृत अधिक विद्यार्थी केन्द्रित बन जाती है। ज्यादातर कार्यक्रम विद्यार्थियों को सूचना के नए क्षेत्रों की खोज के लिए इन्टरनेट पर कुशल बनाते हैं। खोज की यह प्रक्रिया विद्यार्थियों को नई–नई सूचनाओं को जानने के लिए प्रेरित करती है ।

आज इंटरनेट का उपयोग जीवन के सभी क्षेत्रों में बढ़ता ही जा रहा है, जिससे इंटरनेट का विस्तार पूरी दुनिया में तेजी से होता जा रहा है। सरकारी, गैर–सरकारी, स्वास्थ्य, बैकिंग, खेल, समाचार के साथ प्राथमिक, माध्यमिक व उच्च शिक्षा में इंटरनेट अपनी भूमिका को निभा रहा है। इंटरनेट के उपयोग ने विद्यार्थियों के सामने आज उच्च शिक्षा हेतु राह आसान की है। आज न केवल उच्च शिक्षा संस्थानो बल्कि माध्यमिक व प्राइमरी स्कूलों के विद्यार्थियों की भी इंटरनेट से पढ़ाई करने में विशेष रुचि है। इंटरनेट के प्रसार के बाद भारत में सूचना और संचार के क्षेत्र में व्यापक परिवर्तन हुए है। भरत में इंटरनेट सेवाओं के उपभोक्ता अपना ज्ञान बढ़ाने के लिए सभी प्रकार के सूचना स्रोतों तक पहुँच सकते हैं। विकासशील देशों में भारत की गणना उन देशों में

होती है, जहाँ इंटरनेट उपभोक्ताओं की संख्या सबसे अधिक है। भारत में इंटरनेट के प्रसार की सहायता एवं समर्थन मिलने के दो प्रमुख कारण हैं, इनमें प्रथम है जो अंग्रेजी जानते और समझते हैं तथा जो किसी अन्य भाषा की अपेक्षा अंग्रेजी में संचार को प्राथमिकता देते हैं। ऑकड़ों से पता चलता है कि जनवरी 1997 में भारत के करीब 3,138 इंटरनेट होस्ट थे, जो पिछले वर्ष के मुकाबले 298 प्रतिशत अधिक थे। इसे शैक्षिक अनुसंधान कि जनवरी 1997 में भारत के करीब 3,138 इंटरनेट होस्ट थे, जो उससे पिछले वर्ष के मुकाबले 298 प्रतिशत अधिक थे। इसे शैक्षिक अनुसंधान नेटवर्क (एर्नेट) द्वारा केवल शैक्षिक उद्देश्यों के लिए उपलब्ध कराया जा रहा था।[4] यह सेवा देश में इंटरनेट ढाँचा कायम करने और भारतीय इंटरनेट सेवा को अंतरराष्ट्रीय पहुँच में लाने की दिशा में भारत और संयुक्त राष्ट्र विकास कार्यक्रम का पहला संयुक्त प्रयास था।

नवें दशक के मध्य भारत में सूचना प्रौद्योगिकी के क्षेत्र में व्यापक क्रान्ति हुई है, जिसने भारत को अंतरराष्ट्रीय सूचना प्रौद्योगिकी के क्षेत्र में अग्रणी पंक्ति में पहुँचा दिया हैं। देश में सूचना प्रौद्योगिकी की पहचान एक ऐसे एजेंट के रूप में हुई है जो मानव जीवन के सभी क्षेत्रों के सभी पहलुओं में परिवर्तन लाने वाला है और जिसने 21वीं शताब्दी में ज्ञान पर आधारित समाज का निर्माण किया। आज पूरी दुनिया में इंटरनेट का उपयोग हो रहा हैं, भले ही कुछ देशों में यह प्रयोग कम है और कुछ में ज्यादा। भारत की 8 प्रतिशत से कम आबादी इंटरनेट का उपयोग करती हैं। अगर भाषा के आधार में देखा जाये तो इंटरनेट का उपयोग अंग्रेजी भाषा अपना प्रथम स्थान रखती हैं, जिसकी संख्या 56, 50, 04, 126 है। इसके बाद दूसरा स्थान चीनी भाषा का आता है।

शिक्षा के क्षेत्र में इंटरनेट : शिक्षा के क्षेत्र में इंटरनेट का बहुतायत से उपयोग किया जा रहा है। इसकी सहायता से शैक्षिक स्तर पर उन्नति हुई है। आज दुनिया के किसी भी कोने में बैठा विद्यार्थी इसकी सहायता से शिक्षा प्राप्त कर सकता है। ऑनलाइन शिक्षण को सभी प्रकार इलेक्ट्रॉनिक समर्थित शिक्षा और अध्ययन के रूप में परिभाषित किया जाता है, जो विद्यार्थियों के व्यक्तिगत अनुभव, अभ्यास और ज्ञान के संदर्भ में ज्ञान के निर्माण को प्रभावित करता है। ई–शिक्षा में वेब अधारित शिक्षा, कम्प्यूटर आधारित शिक्षा, आभासी कक्षाएँ और डिजिटल सहयोग शामिल है। पाठ्य सामग्रियों का वितरण इंटरनेट, एक्सट्रानेट, ऑडियो–वीडियो टेप, उपग्रह टीवी और सीडी रोम के माध्यम से किया जाता है।

विद्यार्थियों को शिक्षा हेतु अनेक पुस्तकों की आवश्यता होती है, जिन्हे खरीद पाना सबके लिए सम्भव नहीं है। इसके अलावा पुस्तकें महंगी और आसानी से उपलब्ध न होने के कारण विद्यार्थी ऑनलाइन पढना पसंद करते हैं। अतः ऑनलाइन पुस्तकों की उपलब्धता इन सभी विद्यार्थियों को लाभान्वित करती है। आजकल सभी प्रकार की पुस्तकों का विस्तारपूर्वक विवरण इंटरनेट पर उपलब्ध रहता है, जिससे ऑनलाइन बुक्स रीडिंग का अधिक प्रचलन हो गया है। विद्यार्थी अपनी पूरी पढ़ाई इन पुस्तकों का उपयोग करके कर लेते हैं किसी व्यवसाय में रहते हुए यदि आप अपनी शिक्षा जारी रखना चाहते है या आपके पास कक्षा में जाने का समय नहीं है, तो इसके लिए विद्यार्थी दूरस्थ शिक्षा के लिए सम्बन्धित संस्थान में विद्यार्थी ऑनलाइन घर या ऑफिस में बैठे–बैठे अपना अध्ययन जारी रख सकते है। ऑनलाइन परीक्षा भी दे सकते है। इससे शिक्षा की ओर विद्यार्थियों का रुझान तेजी से बढ़ा रहा है ।

ऑनलाइन शिक्षण के क्षेत्र में आज दूरवर्ती शिक्षा प्रणाली का योगदान बढ़ता ही जा रहा है। दूरवर्ती शिक्षा प्रणाली में मल्टीमीडिया एवं इंटरनेट का योगदान अत्यधिक है। बहुत से व्यक्ति पारिवारिक, सामाजिक, आर्थिक और समय न होने के कारण, शिक्षा ग्रहण नहीं कर पाते हैं, लेकिन उनके मन में पढने की आकांक्षा बनी रहती है। इस प्रणाली के जरिए इच्छुक विद्यार्थी को उनके घरों पर ही शिक्षा मुहैया कराई जाती है। इस कार्य में मल्टीमीडिया, ऑडियो–वीडियो कैसेट, सीडी–डीवीडी, टेपरिकार्डर, वीडियो रिकार्डर, रेडियो, सामुदायिक रेडियो, टेलीविजन, ई–मेल, इंटरनेट, एस. एम. एस. एम. एम.एस., वीडियो पत्रिकाएं, टेलीविजन पत्रिकाएं, ज्ञानदर्शन चौनल आदि की मदद ली जाती है। इसमें शैक्षिक गतिविधियों जैसे– प्रवेश, पाठ्य सामग्री पाठ्य–सामग्री घर बैठे विद्यार्थियों को इलेक्ट्रॉनिक मीडिया एवं इंटरनेट के माध्यम से उपलब्ध कराई जाती है।

शिक्षा में टेलीकांफ्रेसिंग का चलन अमेरिका में टेलीविजन तथा टेलीफोन पिक्चर फोन के जरिए 1960 में आरंभ हुआ। कांफ्रेसिंग हेतु कम्प्यूटर व इंटरनेट द्वारा प्रदत्त बहु–माध्यमी सेवाओं का उपयोग किया जाता है। यहाँ हम इंटरनेट सेवाओं द्वारा लिखित सामग्री, रेखाचित्रों आदि को कॉफ्रेसिंग में भाग लेने वाले व्यक्तियों को प्रेषित कर सकते हैं।

ऑडियो–वीडियो कॉफ्रेसिंग, जब कम्प्यूटर टेक्नोलॉजी और इंटरनेट से अच्छी तरहा जुड़ जाती हैं, तो ऐसी टेलीकांफ्रेसिंग शिक्षक और विद्यार्थी दोनों को ही अपनी–अपनी स्वाभाविक रुचियों, समय और साधनों की उपलब्धता तथा सीखने–सीखाने की गति के आधार पर स्व–अनुदेशक एवं स्व–प्रशिक्षण प्रदान करती है। इससे विद्यार्थी शिक्षा के विषय में आपस में संवाद कर सकते हैं। इसके साथ ही आपस में पाठ्य सामग्री के विषय में संवाद कर सकते हैं।

आजकल मोबाइल लर्निंग (एम–लर्निंग) का भी चलन है। आज मोबाइल विद्यार्थियों के साथ 24 घंटे उपलब्ध रहता है, जिससे वह इंटरनेट से हमेशा कनेक्ट रहते हैं। परिणामस्वरूप आज विद्यार्थी मोबाइल सर्विसेज की अति आधुनिक तकनीक का उपयोग ई–बैकिंग, ई–कामर्स तथा ई–लर्निंग में उसी तरह कर सकते हैं जैसे कि कंम्प्यूटरों द्वारा सुलभ इंटरनेट तथा वेब टेक्नोलॉजी द्वारा करते हैं। इस प्रकार से ई–लर्निंग का विगत या भूत है, तो दूसरा मोबाइल लर्निंग भविष्य है।

नौलेज कोशेंट एजूकेशन के डाइरेक्टर भूमा कृष्णन (2007) ने ई–लर्निंग की ऐतिहासिक विवेचना करते हुए जो निष्कर्ष सामने रखे हैं, उनके अनुसार ई–लर्निंग कर विकास जिन चार प्रमुख अवस्थाओं में से गुजरा है, वे हैं (1) मल्टीमीडिया काल (1984–1993), (2) वेब–प्रारंभिक काल (1994–1999), (3) वेब–तकनीक का नया दौर (2000– 2005) तथा वर्तमान समय में उपलब्ध मोबाइल लर्निंग।[5]

वेबसाइट पर ऑनलाइन प्रलेख वितरण सेवाएं विश्व व्यापी रूप से उपलब्ध हैं। इन सेवाओं की सहायता से शोध आलेखों एवं अन्य प्रलेखों की छायाप्रति प्राप्त की जा सकती है।

ई–बुकशॉप : आज इन्टरनेट पर ऑनलाइन बुकशॉप उपलब्ध हैं। जिन पर विद्यार्थी अपनी रुचि के प्रलेखों को खोज सकते हैं। उसके बारे में जानकारी प्राप्त कर सकते है और उन्हे खरीद सकते हैं। इससे विद्यार्थियों को पाठ्य सामग्री के चयन में समय की बचत और आसानी से होती है।

आज सभी प्रकार के प्रमुख प्रकाशकों के होम पेज हैं एवं इन्टरनेट पर इनके द्वारा प्रकाशित पाठ्य सामग्री से सम्बन्धित पूरी जानकारी उपलब्ध है। इसके साथ प्रकाशकों की किताबों को विद्यार्थी ऑनलाइन खरीद सकते हैं। शोध विद्यार्थियों के लिए यह बहुत उपयोगी है।

ई– प्रकाशन : आज जीवन के सभी क्षेत्रों में इंटरनेट ने अपनी पहुँच को आसान किया है। जिससे कि आज इंटरनेट पर किताबों की उपलब्धता में तेजी से बढ़ोत्तरी हुई है। जिससे इंटरनेट पर किताबें तथा पत्र–पत्रिकाएँ प्रकाशित करना या उपलब्ध कराना ई–प्रकाशन कहलाता है और इस तरहा की पुस्तकें ई–बुक्स कहलाती हैं। जिसकों विद्यार्थी मुफ्त में या शुल्क अदा कर पढ़ सकता है। जिसकों आवश्यकतानुसार डाउनलोड भी किया जा सकता है। दिनों–दिन, ई–बुक्स की अधिकता से यह सिद्ध होता है कि विधार्थियों की रुचि इस ओर बढ़ती जा रही है ।

डिजिटल पुस्तकालय : आधुनिक समय में शिक्षा का स्तर तेजी से बदल रहा है। आज इंटरनेट ने विद्यार्थी को कभी भी, कहीं भी सूचना एवं शिक्षा को आसान बना दिया है। विद्यार्थी एक क्लिक पर अपने विषय से सम्बन्धित हजारों जानकारी तक पहुँच सकता है। इंटरनेट ने दुनिया की किसी भी जानकारी तक पहुँच आसान की है। इसमें दुनियाँ की किताबों, शोध–पत्रों ऑनलाइन लाइब्रेरी शोध–ग्रन्थों का अध्ययन विद्यार्थी अपनी रुचि के अनुसार कर सकते है। एक अच्छी लाइब्रेरी में एक कैटलॉग होता है। जिससे पता चल जाता है कि लाइब्रेरी में कौन से डाक्यूमेंट उपलब्ध है और वह किस रैक में हैं। ऑनलाइन शिक्षा के विभिन्न रूप हैं, जिसमें वेब आधारित लर्निंग, मोबाइल आधारित लर्निंग या कंप्यूटर आधारित लर्निंग और वर्चुअल क्लासरूम इत्यादि शामिल हैं।

सन्दर्भ :

1. कुमार, आशुतोष, एण्ड गंगवार, डॉ0 रचना, 2012, शैक्षिक कार्यो में इंटरनेट की भूमिका : एक अध्ययन, कम्यूनिकेशन टूडे, जून 29.
2. चाऊ, ए.एस. एण्ड क्रेक्सोटॉन, आर.ए. 2014, ए यूजबिल्टी इवेन्यूशन ऑफ एकडमिक डिजिटल रिफरेन्स सर्विस, व्यू 16366.
3. जबीर, एन.आई. 2008, इलेक्ट्रानिक रिफरेन्स सर्विस इन एकेडमिक लाइब्रेरिज, जर्नल ऑफ दि कॉलेज ऑफ एजूकेशन वूमेन, वा. 19, इशू 2
4. मुखोपाध्याय, पी.एस. 2013, कोर्सवेयर ऑफ लाइब्रेरी इनफारमेशन टेक्नोलॉजी, प्रोवा प्रोकाशनी, कोलकाता, पृ0 126–118.
5. आशुतोष कुमार एण्ड डा. रचना गंगवार, 2012, शैक्षिक कार्यो में इंटरनेट की भूमिका : एक अध्ययन, कम्यूनिकेशन टूडे, जून पृ0 29.

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Technological study of Paneer prepared from Cow, Buffalo, mixed and standardized milk

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ABSTRACT

Paneer, an indigenous acid-heat coagulated fresh cheese, holds significant importance in Indian cuisine and the dairy industry as a primary protein source for vegetarian populations. This comprehensive study evaluated the technological parameters and quality characteristics of paneer prepared from four different types of milk: cow milk, buffalo milk, mixed milk (equal proportions of cow and buffalo), and standardized milk. The research aimed to determine the optimal milk source for paneer production by analyzing physicochemical properties, sensory attributes, yield efficiency, and nutritional composition. Fresh milk samples were subjected to detailed physical and chemical analyses. The results revealed distinct variations in milk composition that significantly influenced paneer characteristics. Buffalo milk showed the highest fat content, averaging 6.92%, compared to cow milk (3.41%), mixed milk (5.14%), and standardized milk (3.32%). Protein content ranged from 2.56% in mixed milk to 3.03% in standardized milk. These compositional differences led to notable variations in paneer quality and yield.Paneer made from buffalo milk exhibited the highest yield (17.56%) along with superior sensory properties, including a white appearance, smooth texture, and nutty-sweet flavor profile. Mixed milk paneer achieved a comparable yield (17.04%) with balanced sensory characteristics. Cow milk paneer yielded 16.21% and had a light-yellow color with a pleasant acidic taste. Standardized milk paneer, though lower in yield (14.14%), exhibited the highest total solids content (51.55%).Moisture content analysis showed significant differences across samples: cow milk paneer (59.23%), buffalo milk paneer (56.11%), mixed milk paneer (52.05%), and standardized milk paneer (48.16%). Fat content also varied, with standardized milk paneer containing the highest fat (24.09%), followed by mixed milk (24.04%), buffalo milk (23.05%), and cow milk (19.89%). Protein content remained relatively consistent across all variants, ranging from 18.33% to 20.03%. Statistical analysis confirmed significant differences ($p<0.05$) among all milk types for most quality parameters, validating the influence of milk composition on paneer characteristics.The findings indicate that milk type selection should depend on the intended applicationbuffalo milk for premium culinary use requiring superior taste and texture, standardized milk for commercial production demanding higher solids, mixed milk for balanced quality attributes, and cow milk for consumers preferring a lighter flavor profile.

KEYWORDS

Milk sample, Manufacture, Paneer, Yield

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Paneer, a non-fermented fresh cheese, holds a prominent place in Indian cuisine and dairy processing, and its global acceptance continues to grow due to its high nutritional value and versatile culinary applications. Its ability to retain structural integrity during deep frying has made it a favored choice for preparing appetizers such as pakoras and fried paneer cubes (Aneja, 2007). For vegetarians, paneer serves as an affordable and rich source of high-quality animal protein, offering excellent digestibility and a biological value ranging from 80 to 86 (Shrivastava and Goyal, 2007). Moreover, paneer provides significant amounts of fat, vitamins, and essential minerals like calcium and phosphorus, while maintaining a reasonable shelf life under refrigeration (Khan and Pal, 2011). Beyond its nutritional role, paneer has a strong socio-economic significance in the Indian dairy sector. It is widely produced by small-scale vendors, cooperative dairies, and organized private plants, contributing to employment generation and value addition to surplus milk (Singh *et al*., 2018).

In urban centres, paneer-based products such as paneer tikka, paneer bhurji, and ready-to-cook paneer cubes have become integral to the fast food and hospitality industries. In rural areas, paneer manufacture offers an avenue for farmers to stabilize income during flush seasons when liquid milk prices fall (Parmesan and Cattaneo, 2010). The sensory and compositional attributes of paneer depend greatly on the type of milk used. Buffalo milk, with its higher fat, casein and total solids content, generally produces paneer with a firmer body, higher yield and richer flavour compared to cow milk (De *et al*., 2014). Cow milk, having lower fat and different casein micelle characteristics, tends to yield softer and more open-textured paneer with a light yellow colour. Mixed milk and standardized milk are increasingly used by industry to achieve consistent quality and to optimize cost of production (Patel *et al*., 2019). The level of fat, casein, lactose and minerals in milk not only affects the rate and extent of coagulation but also governs moisture retention, texture, and cutting properties of the coagulum (Guinee, 2016).

From a technological standpoint, paneer manufacture involves careful control of heating temperature, acidity, coagulant concentration and pressing conditions. Small deviations in these parameters can lead to defects such as hard and rubbery body, weak and crumbly texture, excessive syneresis, or poor sliceability (Mistry *et al*., 2012). In commercial plants, additional challenges include standardization of milk from different sources, automation of coagulation and pressing, hygienic handling, and extension of shelf life through appropriate packaging and cold storage (Khedkar *et al*., 2016). Therefore, a systematic study on the influence of different milk types on paneer yield and quality has direct implications for both small-scale processors and organized dairies. In this context, the present investigation was carried out to evaluate the effect of using cow, buffalo, mixed and standardized milk on the composition of milk, yield of paneer and its physical, chemical and sensory attributes. The outcomes are expected to help processors select the most suitable milk type for specific product requirements such as high-yield industrial paneer, premium-quality culinary paneer, or balanced paneer for general household use.

Materials and Methods

Experimental Site and Milk Sourcing

The study was carried out in the Dairy Technology Laboratory of Udai Pratap Autonomous College, Varanasi. Pure samples of cow, buffalo, and mixed milk were collected from the college dairy farm under hygienic conditions during the morning milking. Standardized milk was procured from the local organized dairy market, representing commercial milk commonly used by consumers. All samples were transported and handled under chilled conditions to minimize microbial growth and compositional changes before analysis and processing.

Experimental Design

Four milk treatments were evaluated:
T_1: Cow milk
T_2: Buffalo milk
T_3: Mixed milk (1:1 cow and buffalo)
T_4: Standardized milk

Each treatment was replicated thrice on different days using milk collected from routine farm production in order to account for day-to-day variation. The data generated on various qualities attributes of milk and paneer were statistically analyzed using Analysis of Variance (ANOVA) under a Completely Randomized Design (CRD) as described by (Snedecor and Cochran, 1994). Treatment means were compared at 5% level of significance ($p < 0.05$).

Milk Quality Analysis

The initial quality of all milk samples was assessed using a Milk Analyzer available in the laboratory to determine fat, solids-not-fat (SNF), lactose, total solids and protein content. Titratable acidity was measured by standard titration method using N/10 NaOH and phenolphthalein indicator and expressed as percentage lactic acid. The colour, flavour and taste of milk were evaluated organoleptically by a small trained panel, with emphasis on detecting any off-flavours or abnormal odour. These baseline measurements helped in understanding how milk composition varied among treatments and how such variation influenced the final paneer.

Preparation of Paneer

Fresh milk (cow, buffalo, standardized, and mixed), standardized to 6% fat wherever necessary, was pasteurized by heating to 78°C for 20 seconds and promptly cooling to about 35°C. The milk was then heated in a stainless -steel vessel to the boiling point on a gas burner with continuous and gentle stirring using a stainless steel ladle to avoid scorching and to prevent the formation of cream on the surface during heating. After boiling, the vessel was removed from the fire and the milk was cooled to approximately 70°C. A 1% solution of food grade citric acid was added slowly to the milk with constant stirring until complete coagulation occurred and the whey turned light yellowish-green in colour.

Care was taken to maintain the temperature of the whey above 63°C during coagulation in order to obtain a firm and uniform coagulum. The coagulated mass was then collected in a clean muslin cloth and allowed to drain. The cloth-encased coagulum was tied and pressed for about 2-3 hours by applying suitable pressure using stainless steel weights to expel whey and to obtain a compactblock of paneer. After pressing, the paneer blocks were immediately immersed in chilled potable water for about one hour to improve body and texture, reduce surface temperature and remove excess acidity. The blocks were then removed, surface water was allowed to drain off and the paneer was cut into cubes for further evaluation. Paneer samples prepared from the four types of milk (cow, buffalo, mixed and standardized) were analyzed for physical and chemical qualities on the same day.

Sensory Evaluation

Sensory evaluation of paneer was carried out by a semi-trained panel comprising staff and postgraduate students of the Dairy Technology discipline. Paneer cubes were tempered to room temperature and presented to panellists in coded plates under uniform lighting conditions. A nine-point hedonic scale was used to score colour and appearance, body and texture, and flavour, where, 9 indicated “likes extremely" and 1 indicated "dislike extremely". Panellists rinsed their mouths with potable water between samples.

The mean sensory scores were used to compare the overall acceptability of paneer prepared from different milk types.

Yield Determination

Paneer yield was calculated as the weight of paneer obtained per 100 g of milk processed. For each treatment, the quantity of milk taken for coagulation and the corresponding weight of drained and pressed paneer were recorded accurately using an electronic balance. The mean yield and range for each treatment were computed from replicated trials and are presented in table 4. These yield values were interpreted in relation to the original milk composition and final paneer composition.

Results and Discussion

Composition and Quality of Milk

The composition and sensory quality of the different types of milk used for paneer manufacture are summarized in table 1. Buffalo milk contained the highest levels of fat and SNF, followed by mixed milk, while cow milk and standardized milk had comparatively lower fat content. Protein content showed smaller variation but tended to be higher in standardized milk due to adjustment of fat level while retaining casein and serum proteins. The lactose content was highest in standardized and mixed milk, which is desirable for development of mild sweetness and browning reactions in cooked products. The higher fat and SNF content of buffalo milk is in agreement with the typical composition of Indian buffalo milk reported in literature (De *et al*., 2014; Singh *et al*., 2018).

Such a composition favours higher paneer yield and a firmer body because more casein and fat globules are available to form the coagulum network. Similar observations were made by (Patel *et al*., 2019) who reported buffalo milk yielding 18.2% paneer compared to cow milk at 15.8%. On the other hand, cow milk, with lower fat and slightly lower SNF, is expected to give lower yield and a softer body. Mixed milk, prepared by blending cow and buffalo milk, showed intermediate values for most constituents, suggesting that it can be used to obtain balanced paneer with moderate yield and acceptable texture, consistent with findings of (Guinee, 2016).

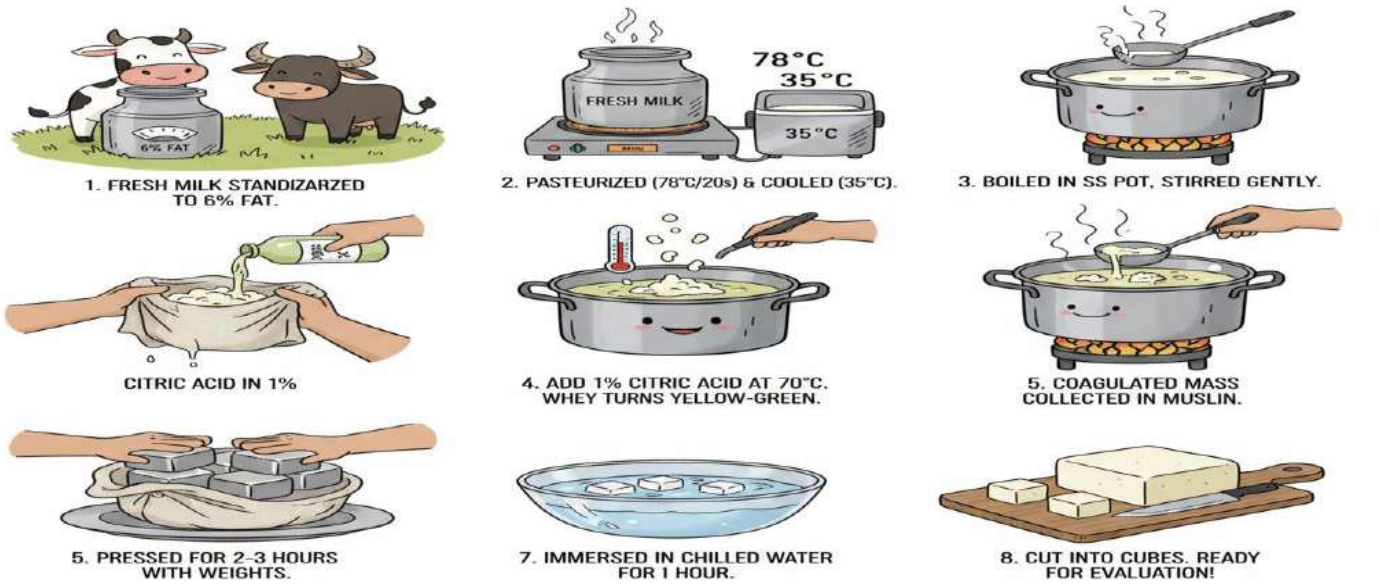

Fig 1. Paneer samples prepared from the four types of milk (cow, buffalo, mixed and standardized) were analyzed for physical and chemical qualities

Table 1. Composition and quality of different types of milk used for the manufacture of paneer

Type	Colour	Flavour	Taste	Acidity	Fat (%)	Protein (%)	Lactose (%)
Cow	Light yellow	Pleasant	Light sweetish	0.155	3.41	2.611	3.91
Buffalo	White	Pleasant	Sweetish	0.161	6.92	2.74	4.09
Mixed	Yellowish white	Pleasant	Light sweetish	0.148	5.14	2.56	4.45
Standardized	White	Pleasant	Light sweetish	0.143	3.32	3.03	4.65

Note: Buffalo milk showed the highest fat content (6.92%), which contributes to higher paneer yield and firmer body texture

Physical Quality of Paneer

The physical quality of paneer prepared using different milk types is presented in table 2. Paneer from cow milk had a light yellow colour and spongy compact body with pleasant sour flavour. Buffalo milk paneer was white, smooth and soft with characteristic nutty sweetish flavour. Mixed milk paneer showed a yellowish white colour with spongy, smooth body and nutty sweetish flavour, while paneer from standardized milk was white but somewhat hard and waxy with pleasant sour taste. The firm yet smooth body of buffalo milk paneer can be attributed to the higher casein content and better fat entrapment in the protein network (De *et al*., 2014). The sponginess observed in cow and mixed milk paneer is likely due to higher moisture retention and more open structure of the coagulum. Standardized milk paneer, though white and visually appealing, became relatively hard and waxy, probably because of its high total solids and lower moisture level, which can reduce juiciness and chewability.

Similar findings were reported by (Singh *et al*., 2018) who observed that paneer made from standardized milk had harder texture with 48.5% moisture compared to cow milk paneer with 59.8% moisture.

Table 2. Physical quality of paneer

Milk Type	Colour	Body/ Texture	Flavour/ Taste
Cow	Light yellow	Spongy compact	Pleasant sour
Buffalo	White	Smooth, soft	Nutty sweetish
Mixed	Yellowish white	Spongy, smooth	Nutty sweetish
Standardized	White	Hard, waxy	Pleasant sour

Chemical Quality of Paneer

The average chemical composition of paneer prepared from different milk types is given in table 3. Cow milk paneer had the highest moisture content (59.23%), followed by buffalo (56.11%), mixed (52.05%) and standardized milk paneer (48.16%). In contrast, total solids were highest in standardized milk paneer (51.55%) and lowest in cow milk paneer (43.77%).

Fat content was highest in paneer prepared from mixed and standardized milk, while protein content ranged between about 18 and 20% across all treatments. The high moisture content of cow milk paneer explains its softer and spongier body. Higher moisture generally improves juiciness but reduces shelf life and may predispose the product to microbial spoilage if not properly refrigerated. Standardized milk paneer, with the lowest moisture and highest total solids, would be expected to have better keeping quality and suitability for cutting, grating and incorporation into industrial formulations. These results align with earlier studies by (Patel *et al*., 2019) that reported cow milk paneer with 58.9% moisture and standardized milk paneer with 49.2% moisture content. The relatively similar protein content in all treatments indicates that milk standardization primarily altered the fat and moisture balance rather than protein level.

Table 3. Average chemical quality of paneer (%)

Type	Moisture (%)	Protein (%)	Fat (%)	Total Solids (%)
Cow	59.23	18.71	19.89	43.77
Buffalo	56.11	19.07	23.05	44.95
Mixed	52.05	20.03	24.04	45.98
Standardized	48.16	18.33	24.09	51.55

Note: Standardized milk paneer showed the highest total solids content (51.55%), while cow paneer had the highest moisture (59.23%), reflecting differences in milk composition and coagulation properties.

Yield of Paneer

The yield performance of paneer from different milk types is shown in table 4. Buffalo milk recorded the highest mean yield (17.56%), followed closely by mixed milk (17.04%) and cow milk (16.21%). Standardized milk gave the lowest mean yield of 14.14% despite its high total solids content. Higher yield from buffalo milk is expected because of its higher fat and casein concentrations, which contribute directly to the dry matter of paneer. Mixed milk also performed well due to the contribution of buffalo milk solids. The relatively lower yield from standardized milk, in spite of its higher total solids in the final paneer, may be related to processing conditions and the way in which fat and protein are distributed in the standardized product.

It is possible that adjustment of fat level altered the firmness of coagulum and the extent of whey retention. These findings are comparable to the study by (De *et al*., 2014) that reported buffalo milk yield of 18.1%, cow milk yield of 15.9%, and mixed milk yield of 17.3%. Mistry *et al*. (2012) also documented that variations in milk composition, particularly fat and casein, are the primary drivers of paneer yield differences among milk types. Overall, the results clearly demonstrate that milk type significantly affects paneer yield, chemical composition and texture. These findings are in line with previous reports that buffalo milk is more suitable for high-yield paneer with rich sensory attributes, while cow milk yields a softer and lighter product preferred in certain culinary preparations.

Table 4. Yield percentage of paneer

Milk Type	Yield Range (%)	Mean Yield (%)
Cow	13.01–19.00	16.21
Buffalo	14.07–21.05	17.56
Mixed	13.05–20.00	17.04
Standardized	10.01–19.06	14.14

Note: Buffalo milk produced the highest mean yield (17.56%), followed by mixed milk (17.04%), while standardized milk showed the lowest yield (14.14%), reflecting differences in milk composition and coagulation properties.

Practical Implications

For small-scale farmers and household processors, selecting buffalo or mixed milk can be advantageous when the objective is to maximize paneer yield and obtain rich, flavourful paneer for direct consumption. For organized dairies targeting the manufacture of paneer for cutting, grating or incorporation into ready-to-eat dishes, standardized milk offers the advantage of higher total solids and a more compact structure, although yield per unit milk may be lower. Cow milk can be preferred where a softer, spongier paneer with mild acidic flavour is desirable, for example in certain North Indian curries and snacks. Khedkar *et al*. (2016) similarly concluded that milk standardization provides consistency for large-scale operations, whereas buffalo milk is preferred for premium paneer products in traditional establishments.

Limitations and Future Scope

The present study was conducted under controlled laboratory conditions using milk obtained from a single institutional farm and one source of standardized market milk.

Variations due to season, breed differences, feeding regimen and geographical area were not captured in this work. The study also focused mainly on physicochemical and sensory attributes of fresh paneer and did not include microbiological assessment or shelf-life evaluation under different storage conditions. Future research could explore the influence of different coagulants (citric acid, lactic acid, vinegar, and microbial coagulants), levels of milk standardization, and fortification with functional ingredients such as whey proteins, dietary fibre or herbs on the quality and yield of paneer. Studies on packaging materials, modified-atmosphere storage and cold chain management would also be useful to extend the shelf life of paneer and to support its distribution to distant markets. In addition, economic analysis comparing the cost-benefit of using different milk types for paneer manufacture under farm and industrial conditions would provide valuable guidance to stakeholders, as suggested by (Parmesan and Cattaneo, 2010).

Conclusion

Paneer quality and quantity are influenced significantly by the type of milk used. Buffalo milk delivers superior sensory and physical attributes, desirable for gastronomic purposes, while standardized milk yields higher total solids suited for industrial-scale production. Mixed milk optimizes both sensory and chemical characteristics, while cow milk, though yielding slightly less, offers a distinct, light, spongy paneer for specific culinary niches. The results of this study suggest that no single milk type is ideal for all situations; rather, the choice should be guided by the intended end use, desired textural properties and economic considerations. This study encourages informed selection of milk sources and processing parameters in paneer production for targeted consumer and industrial needs in the evolving Indian dairy sector.

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References

Aneja, R. P. (2007) East-West fusion of dairy products, In: Gupta S (ed) Dairy India 2007, 6th edn., Dairy India Yearbook, A Dairy India Publication, New Delhi, pp: 51-53.

Cattaneo, T. M. P., Parmesan, A. H. (2010) Functionality of dairy products and their application in dairy technology, *J. Dairy Res*., 77(**3**): 412-421.

De, S., Singhal, R. S., Kulkarni, P. R. (2014) Milk composition and cheese-making properties of buffalo milk, *Adv. Food Nutr. Res*., **68**: 383-409.

Guinee, T. P. (2016) Cheese and related products. In: McSweeney PLH, McNamara JP, Cotter PD (eds) Biochemistry of Milk Products, Academic Press, pp: 297-346.

Khan, S. U., Pal, M. A. (2011) Paneer production: A review, *J. Food Sci. Technol*., 48(**6**): 645-660.

Khedkar, C. D., Rao, V. K., Rao, A. (2016) Technology of milk production and processing, *India Dairy Sci*., 69(**3**): 189-201.

Mistry, V. V., Hassan, H. N., Haenlein, G. F. W. (2012) Advances in dairy technology, *Encyclopedia Food Microbiol*., **2**: 45-52.

Parmesan, A. H., Cattaneo, T. M. P. (2010) Industrial dairy processing: Optimization for milk standardization, *Food Control*, 21(**4**): 456-462.

Patel, R. K., Verma, V. P., Singh, V. K. (2019) Paneer manufacture using different milk types: Yield and quality assessment, *Indian J. Anim. Res*., 53(**7**): 912-918.

Shrivastava, S., Goyal, G. K. (2007) Preparation of paneer, A Review, *Indian J. Dairy Sci*., 60(**6**): 377-388.

Singh, J. P., Verma, A., Kumar, S. (2018) Effect of milk composition on paneer manufacture and quality, *J. Food Sci. Technol*., 55(**9**): 3456-3465.
Snedecor, G. W., Cochran, W. G. (1994) Statistical methods, 8th Edition, Iowa State University Press, Ames.

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NOMOPHOBIA: AN EMERGING PSYCHOLOGICAL DISORDER

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Abstract

Portable technologies especially smart phones have emerged as an advantage for providing a galaxy of opportunity and has steered the society for accessing network, communicating in social circles and gaining knowledge. It has intensified the amount of work and opportunities but excessive use and long-time exposure also brings serious problems. Recently one of the major problems is the excessive usage of mobile or smartphone by the huge population without any specific reason leading to addiction of smart phones from child of early age to adult ones. This is slowly penetrating in human habits and behaviour causing behavioural dependency on electronic gadgets especially smartphones. One of major factor for causing this problematic condition is connection of mobile phone to the internet. Several research reports from different parts of world are indicating the causes, phases of onset of smartphone addiction, consequences and health issues due to the emerging threat of 'no mobile phone phobia' (nomophobia). Therefore, present review is intended to address the current problems associated with nomophobia and the future strategies to overcome its negative impact on society.

Keywords: Nomophobia, Smartphone addiction, psychological variables, Anxiety, CBT

1. Introduction

Mobile phones or smartphones have become the integral part of our life and we are getting dependent on it for almost everything starting from online e-learning, e-commerce, e-governance, e-banking to gaming and entertainment.

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Undefined and excessive usage of mobile phones is associated with increased screen time which is badly impacting the physical as well as psychological health of children, teenagers and adults too[1]. One of the badly emerging psychological dysfunctions associated with smartphones in general public is *Nomophobia*. Nomophobia is an abnormal psychological condition characterised by the fear of not having a mobile phone or for some reason being unable to access it[2]. In general terms, it stands for "No Mobile phone Phobia (*NoMoPhobia*)", a modern pathological condition which may have negative consequences on the physical, physiological, psychological and social well-being. Although the research is in an incipient stage, the problem has impacted various

groups of population and has negative consequences on personal and professional development. Well established causes and phases of onset of mobile phone addiction leading to nomophobia and its symptoms have been presented in **Figure 1.**

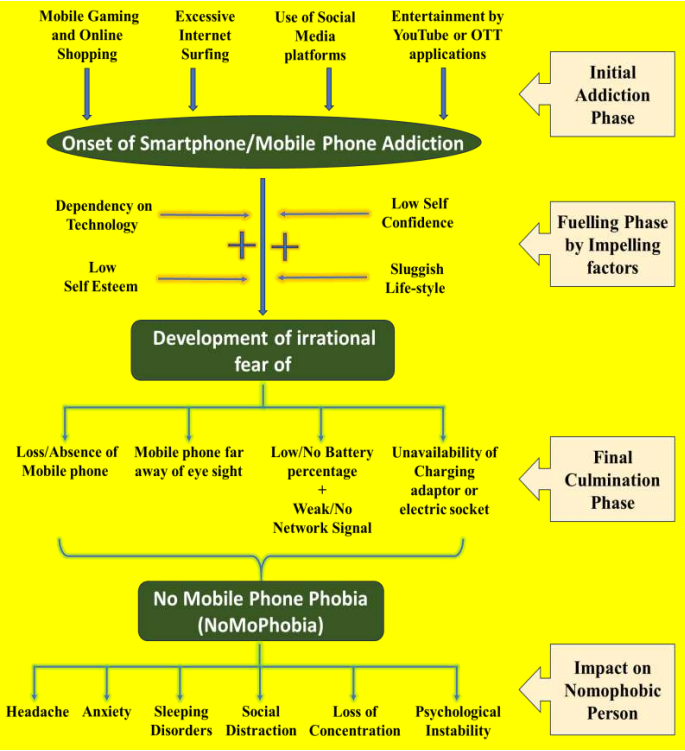

Figure 1. Causes, phases of the development and symptoms of "No Mobile Phone Phobia" (NoMoPhobia).

Nomophobia is a sort of anxiety of being without mobile phone or being unable to use it due to either loss of network signal or low battery. A person with nomophobia invariably feels anxious, insecure, or panicked in the absence of their phone[3]. In this regard, the term "phobia" seems inappropriate here as this psychological condition is much associated with anxiety, fear or panic of being without electronic gadgets. In 2008, an international research and analytics group organisation, 'YouGov' coined this term 'Nomophobia' while studying the impacts of excessive usage of mobile phones and electronic devices on physical, mental and psychological health. Outcome of that survey was alarming as more than 50% of participants realised and confessed nomophobic symptoms like worry of phone loss, no contacts with their loved ones and low battery[4].

2. Conceptualization of Nomophobia

Nomophobia is a term derived from "NO MObile phone PHOBIA," referring to the fear or anxiety experienced when individuals are without their mobile phones or unable to use them[5].This condition has become increasingly prevalent in the digital age, as smartphones have become integral to daily life. This occurrence is expected to rise, emerging as a significant concern, due to the widespread use of smartphones; similarly, the worldwide COVID-19 pandemic has led to increased screen time on these devices[6].

2.1. Causes and Phases of Onset of Nomophobia

Nomophobia has been associated with four key fears: (1) not being able to talk to others, (2) losing internet or signal connection, (3) not being able to find information online, and (4) missing out on the ease that smart phones provide. Mobile addiction through its excessive usage is aggravated by different factors including increased technological dependency, low self-esteem, loneliness, low self-confidence and sluggish lifestyle[7, 8]. Such week emotional and psychological variables act as fuel and impelling factors which culminate mobile addiction into nomophobia **(Fig 1).**

2.2. Sign and Symptoms of Nomophobia

Nomophobia is the collection of signs and symptoms of abnormal psychological and mental status. It has negative impact on several aspects of person's life including family and social relationships, performance on workplace, health, and general well-being[2,3,9]. Nomophobia may manifest as the following symptoms:

- Frequently checking mobile phone for notifications, messages, or calls
- Restlessness or nervousness when the phone is not within visual reach
- Anxiety or stress when the phone battery is low or the signal is poor or absent
- Physical discomfort including palpitation, headaches, eye strain, or neck pain from excessive phone use
- A strong urge to have the phone in hand constantly
- Difficulty in concentration on general tasks or activities in the absence of phone
- Trouble in sleeping or relaxing without the phone
- Negligence in other responsibilities or interests in general talks while using phones
- Impaired social interactions or interpersonal relationships due to phone dependence

After the worsening of condition, nomophobic person may suffer from severe side effects on physical as well as

mental health that includes perspiration, reduced cognition, mental confusion, agitation, loss of patience, disorientation, respiratory dysfunctions, trembling and loss of creativity[10].

3. Global distribution

A scientific investigation across several countries observed prevalence rates of nomophobia ranging from 77% to 99 %, with young ones being the most affected6. In Indian context, a study reported a significantly high proportion of college students experiencing some level of nomophobia, with 32.7% suffering from severe symptoms[11]. In Bahrain, approximately 93% of students experienced moderate to severe symptoms of nomophobia[12]. In an investigation carried out by SecurEnvoy (UK) including 1,000 employees, the percentage of individuals experiencing symptoms of nomophobia were ranging from 53% to 66%[13, 14]. In addition, they also reported that women were more vulnerable to nomophobia, affecting about70% of female participants compared to 61% of their male counterparts.

4. Factors Associated with Nomophobia

There are several reports in which demographic factors were found to influence the frequency and severity of nomophobia in given population. Some of the factors have been discussed in subsequent sections.

- **Age:** Younger population, particularly college and university students, are more susceptible to nomophobia and they are also exhibiting severe nomophobic symptoms compared to adult ones[15].
- **Gender:** According to some studies, females experience higher levels of nomophobia, although findings are mixed and need further investigations on large population covering household as well as working individuals[16].
- **Smartphone Usage Patterns:** Increased levels of nomophobia have been found to be associated with higher daily usage hours and irrational frequent phone checks for massages, time, battery levels and network signal[17].
- **Parental Education and Income:** Severity of nomophobia has not been associated with parental education levels and place of residence[16]. In some countries including India, nomophobia is found prevalent among high income families[18] while in other developed countries, no significant correlation was observed with the income of parents[16].

5. Psychological Correlates and prevailing factors

The impact of nomophobia also can be correlated to psychological status of affected person in terms of different conditions such as depression, stress, insomnia, loss of self-confidence etc. The problem of nomophobia is not limited to this extent but it may also coexist with addictions in the peoples for social media and internet[2,16,19]. The regular addiction of internet badly affects the human health in terms of cognitive overload. The compulsive need to check notifications or remain constantly online contributes to mental and emotional tiredness. Some important aspects of nomophobia on psychological behaviour are being discussed in following subsections.

Stress: A person having nomophobia frequently experience high levels of stress when due to some reasons they are not able to use their mobile phone and it may be expressed as high levels of anxiety and impatience. This anxiety can be reflected as nervousness, or fright in situations where the use of mobile phones is restricted or limited[19].

Depression: Researches have demonstrated the strong correlation between nomophobia and depression in the form of conditions such as sadness, grief, loss of interest in routine work, exhaustion[19].

Loneliness: It has been observed that people addicted with mobile phones and suffering from nomophobia also experience loneliness and become isolated from society[20].

Loss of confidence and poor management approaches: Excessive use of mobile phones on daily basis causes the negative impact on human psychology and related with loss of self-confidence and limited participation in family or societal activities. Stress induced poor and inefficient management skill has also been observed in nomophobic persons[21].

6. Impact of nomophobia on daily activities

Nomophobia has prominent and significant impact on psychological, behavioural as well as social aspects of affected person. Nomophobic individual has been found to be engaged in risky behaviour such as texting while driving, walking, and often using mobile phones in social gathering[2]. Mobile addiction is also linked to reduced academic or work-place performance[20]. It also hinders

face-to-face communication promoting isolation and withdrawal from family and society. Person involved in any profession are suffering from nomophobia issues and they face several problems such as restriction from social environment, limited direct interaction with peoples, having high levels of stress, low levels of concentration, loss of sleep etc[5, 21].

7. Treatment and Intervention Strategies

Effective interventions strategies for managing nomophobia include cognitive-behavioural therapy (CBT), digital detox programs, and mindfulness-based practices[22,23]. In CBT, nomophobic person is able to identify and change negative thought patterns associated with mobile phone usage. Mindfulness techniques involving the meditation and deep breathing practices are found effective to calm the mind while reducing stress and anxiety. Promoting digital literacy, healthy habits and self-discipline may also serve as preventive measures. Mobile applications that track screen time or restrict usage are increasingly used in minimizing the impact of nomophobia[24]. Psychiatric counsellors may assist the affected person also for the treatment of sign and symptoms like anxiety, eye irritation, sleeplessness etc[2,8]. However, pharmacological treatments under severe conditions which may include use of psychotropic drugs are also recommended.

8. Conclusion

NOMOPHOBIA, being a form of behavioural addiction is putting our "social, mental as well as physical well-being" at higher risk. Compared to the virtual world, there is need to spend more time in the real one. Face-to-face communication and in-person relationships must be restored to avoid the development of nomophobia or any other psychological disorder associated with electronic gadgets. One should limit rather than completely prohibit mobile phone use because we cannot undervalue the power of technological advancement.

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References

1. **Wacks Y., Weinstein A.M. (2021)**. Excessive Smartphone Use Is Associated With Health Problems in Adolescents and Young Adults. *Front Psychiatry*. 12:669042. doi: 10.3389/fpsyt.2021.669042.
2. **Bhattacharya S., Bashar M., Srivastava A., Singh A. (2019)**. NOMOPHOBIA: NO Mobile Phone PhoBIA. *J Family Med Primary Care*, *8*(4), 1297.
3. **King A.L., Valença A.M., Silva A.C., Sancassiani F., Machado S., Nardi AE. (2014)**. "Nomophobia": impact of cell phone use interfering with symptoms and emotions of individuals with panic disorder compared with a control group. *Clin Pract Epidemiol Ment Health*. 10:28-35. doi: 10.2174/1745017901410010028.
4. **Nikhita C.S., Jadhav P.R., Ajinkya S.A. (2015).** Prevalence of Mobile Phone Dependence in Secondary School Adolescents. *J Clin Diagn Res.* 9(11): VC06-VC09. doi: 10.7860/JCDR/2015/14396.6803.
5. **Bragazzi N.L., Puente G.D. (2014).** A proposal for including nomophobia in the new DSM-V. *Psychol Res Behav Manag*. 7:155-60. doi: 10.2147/PRBM.S41386.
6. **Tuco K. G., Castro-Diaz S. D., Soriano-Moreno D. R., Benites-Zapata V. A. (2023).** Prevalence of Nomophobia in University Students: A Systematic Review and Meta-Analysis. *Healthc Informs Res*, *29*(1), 40–53.
7. **Basha E., Mustafa A. (2024).** Dataset on the correlation between nomophobia dimensions among university students in Kosovo. *Data Brief.* 55:110766. doi: 10.1016/j.dib.2024.110766.
8. **Shah R., Lakhani S., Shah J., Mbithi A., Singh A., Gandhi Z., Mehta P., Kashyap R., Surani S. (2024).** Nomophobia: a challenge among healthcare professionals in Africa. *Hospital Practice*, 53(1). https://doi.org/10.1080/21548331.2024.2432858
9. **Pandey D., Rosha A. (2024).** Nomophobia: Growing fear of being without smartphone. *Int J Adv Psychiat Nur*. 6(1):110-112.
10. **Goncalves L.L., Bortolanza S.C., Padua M.K., Nardi A.E., King A.L.S. (2021).** Nomophobia in

the last decade: a systematic review. *Mental Health Addict Res.* 6: 1-7. DOI: 10.15761/MHAR.1000203

11. **Bajaj S., Maheshwari S.K., Maheshwari P.S. (2020).** Prevalence of Nomophobia among College Students: An Exploratory Cross-Sectional Survey. *Indian J of Psychiat Nur.* 17(1):p 29-32. DOI: 10.4103/IOPN.IOPN_21_19
12. **Jahrami H., Abdelaziz A., Binsanad L., Alhaj O.A., Buheji M., Bragazzi N.L., Saif Z., BaHammam A.S., Vitiello M.V. (2021)**. The association between symptoms of Nomophobia, Insomnia and Food Addiction among young adults: findings of an exploratory cross-sectional survey. *Int J Environ Res Public Health*. 18(2):711. doi: 10.3390/ijerph18020711.
13. **Nagpal S. S., Kaur R. (2016).** Nomophobia: The problem lies at our fingertips. *Indian J Health & Well.* 7(12).
14. **Yildirim C., Correia A.P. (2015).** Exploring the dimensions of nomophobia: Development and validation of a self-reported questionnaire. *Comput Human Behav. 49*, 130–137.
15. **Alkalash S. H., Aldawsari A. K., Alfahmi S. S., Babukur A. O., Alrizqi R. A., Salaemae K. F., Al-Masoudi R. O., Basamih K. A. (2023).** The Prevalence of Nomophobia and Its Impact on Academic Performance of Medical Undergraduates at the College of Medicine, Umm Al-Qura University, Makkah City, Saudi Arabia. *Cureus*. 15 (12):e51052. doi: 10.7759/cureus.51052.
16. **Sadeghi N., Rezaeian S., Janatolmakan M., Heidarian P., Khatony A. (2025).** Exploring the prevalence of nomophobia, its contributing factors, and the relationship with social interaction anxiety among nursing students. *BMC Med Educ*. 25(1):372. doi: 10.1186/s12909-025-06902-8.
17. **Aslani M., Sadeghi N., Janatolmakan M., Rezaeian S., Khatony A. (2025).** Nomophobia among nursing students: Prevalence and associated factors. *Sci Rep*, *15*(1), 173.
18. **Kaur A., Ani A., Sharma A., Kumari V. (2021).** Nomophobia and social interaction anxiety among university students. *Int J Afr Nurs Sci.* 15:100352.
19. **Santl L., Brajkovic L., Kopilaš V. (2022).** Relationship between Nomophobia, Various Emotional Difficulties, and Distress Factors among Students. *Eur J Investig Health Psychol Educ*. 12(7):716-730. doi: 10.3390/ejihpe12070053.
20. **Agrawal A., Pearlene H.M.D. (2023).** Influence of Nomophobia and Loneliness on Young Adults. *Int J Indian Psychol*. 11: 2654-2667. Doi: 10.25215/1103.252
21. **Anjana K. K., Suresh V. C., Sachin B. S., Poornima C. (2021).** The Relationship between Nomophobia, Mental Health, and Coping Style in Medical Students. *Indian J Soc Psychiat. 37*(2), 207–211.
22. **Chadha Y., Patil R., Toshniwal S., Sinha N. (2024).** Internet Addiction Management: A Comprehensive Review of Clinical Interventions and Modalities. *Cureus*, 16(3):e55466. doi: 10.7759/cureus.55466.
23. **Wang H., Chen X. (2023).** Intervention Effect of Mindfulness-Based Mental Health Education Therapy on Adolescents Mobile Phone Addiction and Cognitive Tendency. *Iran J Public Health*. 52(12):2563-2571. doi: 10.18502/ijph.v52i12.14317.
24. **Canadian Paediatric Society, Digital Health Task Force, Ottawa, Ontario (2019).** Digital media: Promoting healthy screen use in school-aged children and adolescents. *Paediatr Child Health*, 24(6):402-417. doi: 10.1093/pch/pxz095.

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अनु 370 के उत्पति की ऐतिहासिक और राजनीतिक परिस्थितयां - एक अध्ययन

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ABSTRACT

अनुच्छेद 370, भारतीय संविधान का एक अस्थायी प्रावधान था, जिसकी उत्पति कुछ विशेष ऐतिहासिक और राजनीतिक परिस्थितियों के कारण हुयी। इस अनुच्छेद के कारण जम्मू-कश्मीर को अन्य राज्यों की तुलना में कुछ विशिष्ट अधिकार तथा स्वायत्तता प्राप्त थी, जो भारतीय संघ के उत्कृष्टता में एक बाधक के रूप में प्रकट हो रहा था। यद्यपि जब अनुच्छेद 370 की मांग शेख अब्दुल्ला के द्वारा की गयी तो इस मांग को स्वीकार्यता देते समय जवाहरलाल नेहरू की सोच थी कि यह बहुत ही शीघ्र निष्प्रभावी हो जायेगा तथापि यह प्रावधान सात दशकों तक प्रभावी रहा। अन्ततः 05 अगस्त 2019 को केन्द्र सरकार ने एक दृढ़ निर्णय लेते हुए इस अनुछेद को निष्प्रभावी कर दिया और एक नये संवैधानिक आयाम का प्रारम्भ किया।

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15 अगस्त 1947 को भारत देश स्वतन्त्र हुआ, परन्तु देश की स्वतन्त्रता के साथ-साथ देश को विभाजन का दंश भी प्राप्त हुआ। देश के विभाजन की यह योजना माउन्टबेटन योजना के तहत् किया गया था, जिसमें यह प्रावधान था कि कोई भी देशी रियासत अपनी इच्छानुसार भारत या पाकिस्तान में विलय कर सकता है एवं यदि किसी देशी रियासत की इच्छा इन दोनों ही राज्यों में विलय की नहीं है तो वह स्वयं को स्वतन्त्र राष्ट्र घोषित कर सकता है। इसी योजना के तहत् जम्मू-कश्मीर के महाराजा हरिसिंह ने स्वयं को स्वतन्त्र राष्ट्र घोषित कर दिया। परन्तु इन्ही परिस्थितियों के मध्य और जम्मू-कश्मीर की कमजोर स्थिति का फायदा उठाते हुए पाकिस्तान ने बलपूर्वक जम्मू-कश्मीर को अपने क्षेत्र में मिलाने का प्रयास किया। इस हेतु पाकिस्तान ने कबाइलियों को तैयार किया एवं यह रणनीति बनायी कि पाकिस्तानी सैनिकों के सहयोग से ये कबाइली जम्मू-कश्मीर राज्य पर आक्रमण में अग्रणी भूमिका निभायेंगे। अन्ततः 20 अक्टूबर 1947 को इन कबाइलियों

ने जम्मू-कश्मीर राज्य पर आक्रमण कर दिया। महाराजा हरिसिंह के सेनापति राजेन्द्र सिंह ने इस आक्रमण को निष्फल करने का अत्यधिक प्रयास किया परन्तु वे सफल नहीं हुए और इस युद्ध में बलिदान हो गये। महाराजा हरिसिंह समझ चुके थे कि स्थितियां अत्यधिक प्रतिकूल हो चुकी है और आगे और भी ज्यादा भयानक हो सकती है। इन्हीं विकट परिस्थितियों में महाराजा हरिसिंह ने 26 अक्टूबर 1947 को विलय-पत्र पर हस्ताक्षर कर जम्मू-कश्मीर का भारत में विलय कर दिया। अगली सुबह 27 अक्टूबर 1947 को भारतीय सैनिकों ने मोर्चा सम्भाल लिया और जम्मू-कश्मीर को इन आक्रामक कबाइलियों और पाकिस्तानी सैनिकों से मुक्त कराने के कार्य में संलग्न हो गये। महाराजा हरिसिंह ने विलय-पत्र पर हस्ताक्षर करने के साथ-साथ शेख अब्दुल्ला को अंतरिम सरकार का गठन करने के लिए आमन्त्रित भी किया। वस्तुतः शेख अब्दुल्ला तात्कालिक समय में जम्मू-कश्मीर के लोकप्रिय नेता होने के साथ-साथ लोकतान्त्रिक मूल्यों के पोषक तथा जम्मू-कश्मीर के भारत में विलय के प्रबल समर्थक थे और इस हेतु अपने विचारों को जनसमर्थन प्राप्त करने के उद्देश्य से नेशनल कान्फ्रेंस नामक पार्टी का गठन किया था।वस्तुतः 26 अक्टूबर 1947 को महाराजा हरिसिंह द्वारा हस्ताक्षरित विलय-पत्र को पाकिस्तान किसी भी स्थिति में स्वीकार नहीं कर रहा था और जम्मू-कश्मीर में अशान्ति और युद्ध को जारी रखा। भारत-पाकिस्तान विवाद को सुलझाने के उद्देश्य से 01 नवम्बर 1947 को लार्ड माउन्टबेटन लाहौर गये तथा वहां पर उन्होंने जिन्ना से मुलाकात की। इस मुलाकात में माउन्टबेटन ने कश्मीर, जूनागढ़ और हैदराबाद में उत्पन्न समस्याओं के समाधान हेतु एक सलाह दिया, जिसके अनुसार - जिन राज्यों में बहुसंख्यक जनता और शासक के धर्म अलग-अलग हों और शासक ने उस अधिराज्य में विलय का फैसला लिया है, जहां की बहुसंख्या का धर्म उस राज्य की बहुसंख्या के धर्म से अलग हो, ऐसे राज्यों में विलय का फैसला जनमत संग्रह कराया जायेगा।[1] परन्तु इस सलाह पर जिन्ना किसी भी स्थिति में तैयार नहीं थे, जिन्ना की सोच थी कि जम्मू-कश्मीर में शेख अब्दुल्ला और भारतीय सेना की जब तक उपस्थिति रहेगी, तब तक इस क्षेत्र की जनता निडर होकर मतदान नहीं कर सकती है। इसीलिए जिन्ना ने शर्त रखा कि जनमत संग्रह, माउन्टबेटन तथा उसके स्वयं के देखरेख में हो। किन्तु इस कार्य के लिए माउन्टबेटन ने अपनी प्रशासनिक एवं संवैधानिक स्थिति स्पष्ट करते हुए कहा कि ऐसा नहीं हो सकता और संयुक्त राष्ट्र के तत्वावधान में जनमत संग्रह कराने का प्रस्ताव दिया लेकिन जिन्ना इसके लिए तैयार नहीं हुए।[2]

इसी क्रम में 02 नवम्बर 1947 को जवाहरलाल नेहरू ने एक भाषण में इस बात का सन्देश दिया कि जैसे ही जम्मू-कश्मीर में स्थितियां सामान्य होगी, तत्काल इस क्षेत्र में जनमत संग्रह कराया जायेगा एवं जम्मू कश्मीर के भविष्य का फैसला इसी जनमत संग्रह के आधार पर किया जायेगा। जवाहर लाल नेहरू को उम्मीद थी कि जम्मू-कश्मीर में स्थितियां जल्द ही सामान्य हो जायेगी परन्तु उनकी आशाओं के विपरीत इस क्षेत्र की स्थितियां अत्यधिक प्रतिकूल होती गयी। नेहरू जी एक आदर्शवादी नेता थे, जिनको संयुक्त राष्ट्र संघ जैसे अन्तर्राष्ट्रीय संस्थाओं पर अत्यधिक विश्वास था। जम्मू-कश्मीर में शान्ति निर्माण के उपायों की खोज में ही जवाहर लाल नेहरू जी ने 31 दिसम्बर 1947 को संयुक्त राष्ट्र

संघ में उल्लिखित व्यवस्थाओं के अध्याय-6 के तहत इस मामले को प्रेषित किया। इस अध्याय के तहत संयुक्त राष्ट्र संघ में प्रेषित दो देशों के विवादों का निपटान शान्तिपूर्ण ढंग से किये जाने के प्रावधानों का उल्लेख मिलता है परन्तु यहां यह भी उल्लेखनीय है कि ऐसे निर्णयों को मानना भी दोनो ही देशों के लिए बाध्यकारी नहीं होगा। संयुक्त राष्ट्र संघ में मामला प्रेषित होने के साथ ही भारत ने जम्मू-कश्मीर के लोगों के लिए जनमत संग्रह की वचनबद्धता को पुनः दुहराया और यह भी कहा कि इस जनमत संग्रह को किसी अन्तर्राष्ट्रीय संस्था की निगरानी में पूर्ण निष्पक्षता के साथ कराया जायेगा लेकिन ऐसा तभी हो सकता है, जब इस क्षेत्र को हमलावरों से पूर्णरुपेण खाली करा लिया जाएगा।[3] इसी क्रम में 21 अप्रैल 1948 को संयुक्त राष्ट्र संघ का संकल्प में आया, जिसमें युद्ध विराम समझौता एवं संघर्ष की समाप्ति का उल्लेख किया गया। अन्ततः 31.12.1948 को संघर्ष विराम हुआ और 01.01.1949 से युद्ध स्थगित हो गया और इस स्थगन के दिन भारत और पाकिस्तान जिस भी स्थान पर थेे उसे ही लाइन ऑफ कन्ट्रोल (एल०ओ०सी) कहा गया। वस्तुतः इस युद्ध विराम के साथ ही जम्मू-कश्मीर व्यावहारिक रूप से दो हिस्सों में बंट चुका था- भारतीय प्राधिकार वाली कश्मीर घाटी, लेह और जम्मू. तथा पाकिस्तान प्राधिकार में आजाद कश्मीर तथा गिलगिट और बाल्टिस्तान।[4]

जम्मू-कश्मीर की स्थितियों की समीक्षा हेतु 15 और 16 मई 1949 को एक बैठक दिल्ली में हुआ। यह बैठक शेख अब्दुल्ला, सरदार बल्लभभाई पटेल तथा जवाहरलाल नेहरू के मध्य हुआ और इसी बैठक के माध्यम से जम्मू-कश्मीर के 04 व्यक्तियों को संविधान सभा में शामिल करने का निर्णय लिया गया। 20 जून 1949 को महाराजा हरिसिंह ने अपने पुत्र कर्णसिंह को राजप्रमुख नियुक्त किया और स्वयं सत्ता से हटने की घोषणा की। शेख अब्दुल्ला की सिफारिश पर कर्ण सिंह ने संविधान सभा में 04 प्रतिनिधि नियुक्त किये। ये 04 प्रतिनिधि-शेख मोहम्मद अब्दुल्ला, मिर्जा अफजल वेग, मौलाना मोहम्मद सईद, मसूदी तथा मोतीराम बागड़ा थे।

वस्तुतः भारत संघ में शामिल सभी देशी रियासतों के विलय-पत्र की भाषा लगभग एक ही समान थी, जिसमें सिर्फ रक्षा, विदेशी सम्बन्ध तथा संचार के विलय का उल्लेख था, किन्तु कालान्तर में इन्होंने भारतीय संविधान को पूर्णतः अंगीकृत कर लिया। किन्तु कर्णसिंह ने उद्घोषणा की कि जम्मू-कश्मीर में भारत का संविधान सिर्फ उन विषयों में लागू होगा जो विलय पत्र के परिशिष्ट में निर्दिष्ट किये गए है।[5] वास्तव में शेख अब्दुल्ला का पूर्ण प्रयास इस बात पर था कि महाराजा हरिसिंह द्वारा विलय पत्र में सौपे गये तीन विषय-रक्षा, विदेशी मामलें तथा संचार, को छोड़कर अन्य विषयों का भारत एवं जम्मू-कश्मीर के अर्न्तसम्बन्धों हेतु भारतीय संविधान में विशेष प्रावधान होने चाहिए और अपने इस प्रयास को प्राप्त करने के लिए एक विशेष व्यवस्था का प्रावधान करने वाले प्रारूप का निर्माण शेख अब्दुल्ला की अगुवाई वाली नेशनल कान्फ्रेन्स द्वारा तैयार किया गया। शेख अब्दुल्ला का विचार था कि जम्मू- कश्मीर को अन्य देशी रियासत वाले राज्यों की तरह व्यवहार न किया जाये क्योकि जम्मू-कश्मीर की एक अलग भौगोलिक, सांस्कृतिक और धार्मिक विशिष्टता

व पहचान है। अतः जम्मू-कश्मीर के लिए एक विशेष प्रावधान की व्यवस्था संविधान में होनी चाहिए। इस हेतु भारत के प्रधानमंत्री जवाहरलाल नेहरू प्रारम्भ में इस आशंका में थे कि यदि जम्मू-कश्मीर की तात्कालिक परिस्थितियों को दृष्टिगत रखते हुए विशेष प्रावधान की व्यवस्था नहीं की जाती तो जम्मू कश्मीर की सरकार तथा जनता का भारत पर पूर्ण विश्वास नहीं हो पायेगा। परन्तु इन सबके मध्य पं० जवाहरलाल नेहरू भारतीय संविधान की महत्ता एवं आदर्श तथा राष्ट्र की एकता तथा अखण्डता को भी अक्षुण्य रखना चाहते थे। अन्ततः इन दुविधाओं के मध्य 18 मई 1949 को शेख अब्दुल्ला को जवाहर लाल नेहरू ने एक पत्र प्रेषित किया जिसने उल्लिखित था कि जम्मू कश्मीर विदेशी मामलों, सुरक्षा तथा संचार के क्षेत्र में भारत के साथ जुड़ गया है। अन्य मामलों में जम्मू कश्मीर राज्य की संविधान सभा, जब बुलाई जायेगी, तब तय करेगी कि किन मामलों में राज्य भारत से जुड़ सकता है।[6] इसी क्रम में जवाहर लाल नेहरू जी ने गोपालस्वामी आयंगर को बिना किसी विभाग के मंत्री बनाया तथा जम्मू-कश्मीर सम्बन्धी मामलों का प्रभारी बनाया।

इस हेतु गोपालस्वामी आयंगर ने शेख अब्दुल्ला तथा पं० जवाहरलाल नेहरू के बीच मध्यस्थ की भूमिका बनायी और भारतीय संविधान में जम्मू-कश्मीर के विशिष्ट प्रावधान के विषय में उन तथ्यों की खोज करने का प्रयास किया जिससे कि दोनों ही पक्षों को संतुष्ट किया जा सके। जम्मू-कश्मीर के विशिष्ट प्रावधान का भारतीय संविधान में उल्लेख किये जाने के डा० भीमराव अम्बेडकर विरोधी थे। अतः उन्होने भारतीय संविधान के प्रारूप की रुपरेखा में इस विषय के निर्माण से असहमति जाहिर की। अन्ततः जम्मू-कश्मीर के लिए विशेष व्यवस्था बनाने वाले प्रावधान के प्रारूप निर्माण की जिम्मेदारी आयंगर को सौंपी गयी। गोपालस्वामी आयंगर को ब्रिटिश भारत में प्रशासनिक पदों को सम्भालने का एक लम्बा अनुभव था और वे 1937 से 1943 तक जम्मू-कश्मीर के प्रधानमंत्री भी रहे थे। अतः गोपालस्वामी आयंगर न केवल प्रशासनिक कार्यों के लिए दक्ष व्यक्ति थे वरन् जम्मू-कश्मीर मामलों का व्यावहारिक अनुभव भी रखते थे। इसी कारण पं० जवाहरलाल नेहरू को उनकी योग्यता, दक्षता तथा अनुभव पर पूर्ण विश्वास था। अन्ततः शेख अब्दुल्ला से प्राप्त प्रारूप में आंशिक संशोधन करते हुए गोपालस्वामी आयंगर ने 17 अक्टूबर 1949 को संविधान सभा के पटल पर जम्मू-कश्मीर के लिए विशेष व्यवस्था का उल्लेख करने वाले अनुच्छेद 306 (अ) को रखा जो कि कालान्तर में अनुच्छेद 370 का रूप धारण कर लेता है। जब आयंगर जी ने अनुच्छेद 306 (अ) का प्रारूप संविधान सभा के पटल पर रखा तो प्रश्न पूछने की श्रृंखला में प्रथम प्रश्न मौलाना हसरत मोहानी का था। इसके अलावा सरदार बल्लभभाई पटेल तथा अनेक संविधान सभा के सदस्य, अनुच्छेद 370 को लेकर सशंकित थे परन्तु गोपालास्वामी आयंगर अपने विस्तृत भाषण द्वारा यह समझाने में सफल रहे कि अनुच्छेद 306 (अ) (अन्ततः अनुच्छेद 370) की आवश्यकता क्यों और किन परिस्थितियो के अधीन है? आयंगर ने अपने भाषण में बताया कि जम्मू कश्मीर के हालात अभी भी सामान्य नहीं है। जम्मू-कश्मीर राज्य को छोड़कर, बाकी सभी राज्यों के संविधानों को, सम्पूर्ण भारत के संविधान में समाविष्ट कर लिया गया है। किन्तु कश्मीर के विशेष हालातों की वजह से विभेदन है। यह विशेष राज्य इस तरह के एकीकरण के लिए अभी भी परिपक्व नहीं है।[7] इसके अतिरिक्त आयंगर

द्वारा प्रस्तुत किये गये उत्तर में दो बातों का प्रमुख रूप से उल्लेख प्राप्त होता है- पहला तो अनुकूल परिस्थितियां होने पर जनमत संग्रह द्वारा कश्मीर राज्य में भारत संघ के साथ सम्बन्धों को स्पष्ट करने का वचन एवं दूसरा यह कि अनुच्छेद 370 का भविष्य राज्य की संविधान सभा तय करेगी।[8]

यदि हम भारतीय संविधान के अनुच्छेद 370 पर दृष्टिपात करें तो हमें निम्न बातों की विवेचना प्राप्त होती है। अनुच्छेद 370 के 4 उपखण्ड है-

(1) प्रथम उपखण्ड में 04 भागों का उल्लेख मिलता है, जिसका अभिप्राय निम्न है-

(क) अनु 238 के उपबन्ध जम्मू-कश्मीर राज्य के सम्बन्ध में लागू नहीं होगा। वस्तुतः भारतीय संविधान के द्वारा 4 प्रकार के राज्यों का बंटवारा किया गया था जिसमें से अनुच्छेद 238 भाग-7 में 'ब' प्रकार के राज्यों को चिन्हित करता है, जिसमें राज प्रमुखों द्वारा शासित देशी रियासतों का उल्लेख मिलता है। जम्मू कश्मीर भी इसी भाग में शामिल किया गया, किन्तु इस भाग के प्रावधान जम्मू-कश्मीर राज्य पर लागू नहीं होगे ।

(ख) भाग-ख से यह जानकारी प्राप्त होती है कि भारतीय संसद के पास जम्मू-कश्मीर के सन्दर्भ में कितनी शक्तियाँ प्राप्त रहेगी? इस हेतु निम्न बातों का उल्लेख मिलता है-

(i) संघ सूची और समवर्ती सूची के वे विषय, जिनका सम्बन्ध विलय-पत्र में घोषित विषयों (रक्षा, वैदेशिक सम्बन्ध एवं संचार) से है, के सम्बन्ध में विधि बनाने के लिए राष्ट्रपति, उस राज्य की सरकार से परामर्श करेंगे ।

(ii) अन्य विषयों को लागू करने के लिए राष्ट्रपति को राज्य सरकार से सहमति लेनी होगी।

(ग) भारतीय संविधान के केवल दो ही अनुच्छेद (अनुच्छेद 1 तथा अनुच्छेद 370) जम्मू-कश्मीर राज्य में लागू होगे।

(घ) इसके अतिरिक्त किसी अन्य उपबन्ध की व्यवस्था राष्ट्रपति के आदेश से लागू हो सकती है, परन्तु रक्षा, वैदेशिक सम्बन्ध तथा संचार के मामले में जम्मू-कश्मीर सरकार से परामर्श लेना होगा तथा अन्य विषयों से सम्बन्धित मामलों में राज्य सरकार की सहमति लेनी होगी।

(2) द्वितीय खण्ड इस बात का उल्लेख करता है कि यदि जम्मू-कश्मीर की सरकार ने किसी मामले में भारत-सरकार को सहमति प्रदान की है तो उस पर अन्तिम रूप से स्वीकार्यता जम्मू-कश्मीर की संविधान सभा देगी।

(3) तृतीय खण्ड उल्लिखित करता है कि राष्ट्रपति लोक अधिसूचना द्वारा घोषणा कर सकते है कि यह अनुच्छेद प्रवर्तन में नहीं रहेगा परन्तु राष्ट्रपति द्वारा ऐसी अधिसूचना निकाले जाने से पूर्व उस राज्य की संविधान सभा की सिफारिश आवश्यक होगी।

अनुच्छेद 370 को भारतीय संविधान के भाग-21 में शामिल किया गया, जो कि अस्थायी, संक्रमणशील तथा विशेष उपबन्धों की व्यवस्था करता है। इसी कारण लोगों की सामान्य धारणा यही बनी कि उक्त अनुच्छेद सिर्फ कुछ ही दिनों के लिए बनाया गया है और समय के साथ ही यह स्वतः निष्प्रभावी हो जायेगा।[9] 26 जनवरी 1950 को भारतीय संविधान लागू होने के साथ ही अनु 370 लागू कर दिया गया। इसी क्रम में 31 अक्टूबर 1951 को जम्मू कश्मीर की संविधान सभा की स्थापना हुयी। 17 नवम्बर 1956 को जम्मू-कश्मीर का संविधान अंगीकृत किया गया तथा 26 जनवरी 1957 को यह लागू कर दिया गया और इसी के साथ अनुच्छेद 370 को समाप्त करने की सिफारिश किये बिना ही यह संविधान सभा भंग हो गयी। इसके पश्चात् अनुच्छेद 370 से सम्बन्धित अनेक विवाद, सन्देह और समस्याएं भी आती रही। वस्तुतः अनु 370 (3) के अनुसार अनु 370 की निष्प्रभाविकता के लिए संविधान सभा की सिफारिश आवश्यक थी। अतः अनेक संविधानविज्ञों ने भी यह कहना प्रारम्भ कर दिया था कि अब इसके निष्प्रभाविकता का कार्य अत्यधिक दुरूह है। किन्तु 05 अगस्त 2019 को केन्द्र सरकार ने जम्मू-कश्मीर की विधानसभा को संविधान सभा मानते हुए अनु 370 को निष्प्रभावी कर दिया। चूंकि तात्कालिक समय में जम्मू-कश्मीर राज्य ने अनु 356 के तहत् राष्ट्रपति शासन लागू था जिसके तहत् विधानसभा की शक्तियां संसद में निहित हो जाती है। अतः संवैधानिक प्रावधानों के तहत इस कार्य के लिए संसद की सहमति प्राप्त की गयी थी।

निष्कर्षतः उपरोक्त विवेचन से यह ज्ञात होता है कि अनुच्छेद 370 न तो पूर्वनियोजित था और न ही पूर्वानुमानित, लेकिन राजनैतिक व ऐतिहासिक समयचक्र यथा-महाराजा हरिसिंह द्वारा ससमय विलय न करना, शासक की कमजोर स्थिति का फायदा उठाते हुए कबायली हमला और युद्ध, कालान्तर में शेख अब्दुल्ला का स्वायत्तता प्राप्त करने की प्रबल मांग, भारत का अन्तर्राष्ट्रीय पटल पर आदर्शवाद को प्रश्रय आदि ऐसे कारण थेे जो कि अनुच्छेद 370 के निर्माण की रुपरेखा बनाते चले गये और इस हेतु किसी ने यह भी नहीं सोचा था कि यह अनुच्छेद इतने लम्बे समय तक प्रभावी रहेगा। वर्तमान में अनुच्छेद 370 निष्प्रभावी हो चुका है और एक नये जम्मू-कश्मीर का उदय होता दिख रहा है जिसमें न केवल नवीन राष्ट्रीय चेतना, आर्थिक, सामाजिक, राजनीतिक विकास प्रतिबिम्बित हो रहा है वरन् जम्मू-कश्मीर के चहुंमुखी विकास का मार्ग भी प्रशस्त हो रहा है।

सन्दर्भ ग्रन्थ:-

1. पृष्ठ 72, वार एण्ड डिप्लोमेसी इन कश्मीर (1947-48), सी० दासगुप्ता,सेज पब्लिकेशन, दिल्ली-2014

2. पृष्ठ 270, मिशन विद माउन्टबेटन, एलन कैम्पवेल जॉनसन, जैको पब्लिशिंग हाउस, दिल्ली- 1951

3. पृष्ठ 17, कश्मीर आफ्टर इंसरजेंसी, बलराज पुरी, ओरियेंट लॉन्गमैन प्राइवेट लिमिटेड, तीसरा संस्करण दिल्ली- 2008

4. पृष्ठ 116-17, कश्मीर: बिहाइंड द वेल, एम॰जे॰ अकबर, रोली बुक्स, छठा संस्करण, दिल्ली-2011

5. पृष्ठ 40-42, स्पेशल स्टेट्स ऑफ जम्मू एण्ड कश्मीर, खुर्शीद अहमद भट्ट, एडूक्रियेशन पब्लिशिंग, दिल्ली - 2015

6. पृष्ठ 51, आर्टिकल 370, ए०जी० नुरानी, आक्सफोर्ड यूनिवर्सिटी प्रेस, पेपरबैक संस्करण, दिल्ली- 2014

7. पृष्ठ 66-67, आर्टिकल 370, ए०जी० नुरानी, आक्सफोर्ड यूनिवर्सिटी प्रेस, पेपरबैक संस्करण, दिल्ली 2014

8. पृष्ठ 47-49, स्पेशल स्टेट्स ऑफ जम्मू एण्ड कश्मीर, खुर्शीद अहमद भट्ट, एड्रक्रियेशन पब्लिशिंग दिल्ली- 2015

9. पृष्ठ 323, कश्मीरनामा, अशोक कुमार पाण्डेय, राजपाल एण्ड सन्स, आठवां संस्करण, दिल्ली-2024

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THE ETHNOBOTANICAL AND PHARMACOLOGICAL EFFICACY OF *ANNONA MURICATA* EXTRACTS, DECOCTIONS

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Abstract

Annona muricata (*A. muricata* Linn.) is an evergreen tree that grows luxuriantly in tropical and sub-tropical regions of the world, the plant also known as guanabana, soursop, or graviola is from the Annonaceae family, valued for both its edible fruit and traditional medicinal uses across Africa and South America. Each portion of this tree from roots to leaveshas been used in folk remedies to cure health related issues such as cancer, ulcers, diabetes, infections, inflammation, and hypertension. Traditional use of this plant has motivated researchers to evaluate its pharmacological efficiency which lead to the validation of its potential. Extensive research has revealed that *A. muricata* have wide range of pharmacological activities and can be used against inflammation, microbial infection, oxidative stress, cancer and diabetes. Apart from this it can be also used in skin related issues, gastrointestinal complication, hepatic complication, hepatic-protection, wound healing, as analgesic and antipyretic agent.

The credit for the medicinal effects of *A. muricata* goes to its rich phytochemical profile, especially acetogenins, alkaloids, phenols, and flavonoids, with over 200 compounds identified. *A. muricata* shows particular promise in cancer and diabetes treatment, with mechanisms such as enzyme inhibition (α-glucosidase, α-amylase), insulin stimulation, and glucose uptake enhancement contributing to its hypoglycemic effects. The leaves of the plant is of particular interest and have been analyzed extensively, it has anti-inflammatory potential and can be a good source for developing an anticancer agent due to presence of wide range of bioactive compounds. However, despite these benefits, some compounds mainly acetogenins and certain alkaloids have shown neurotoxic effects in laboratory models, underscoring the need for careful dosage evaluation and safety assessment. This article elaborates the ethnobotanical and pharmacological importance of the plant.

Keywords:*Annona muricata*, Ethnobotanical, Pharmacology, Plant extracts.

Introduction

A.muricata L., also referred to as soursop or graviola in some parts of the world, is a tropical, evergreen, fruit-BearingAnnonaceae family tree commonly found throughout Southeast Asia, South America, and rainforests in Africa. Preferring temperature and humid conditions, the plant grows well below 1200 meters above sea level under the best conditions of 25-28 °C temperature and 60–80% relative humidity[1]. Historically esteemed in different cultures, practically all components of the plant its fruit, leaves, bark, seeds, and roots have been utilized in ethnomedicine to cure conditions as diverse as skin diseases, abscesses, external as well as internal parasitic infections to gastrointestinal disorders,

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diabetes, hypertension and cancer[2]. Various studies have confirmed utilization of soursop in different conditions such as antidiabetic, anti-inflammatory, antiulcer, antiprotozoal, and antimicrobial action. These pharmacological characteristics of plant are directly attributable to bioactive compounds such as acetogenins, flavonoids, alkaloids, and phenolic compounds contained within it. In addition, contemporary researchers have well documented the pharmacological potential by strict experimentation[3]. During the past several decades, several studies (in vivo and in vitro) have widely documented the pharmacological potential of the plant. It shows high antioxidant activity in tackling oxidative stress and strengthening the body's endogenous antioxidant defense systems. Its antidiabetic activity is witnessed through modulation of carbohydrate-metabolizing enzymes and oxidative stress mechanisms. Scientific evidence and traditional knowledge also attest to its antidiarrheal and antiulcer uses, presumably because of its gastroprotective and motility-controlling constituents[1, 2].

The antimicrobial activity of *A. muricata* covers bacteria, fungi, protozoa, and viruses, thus being a powerful resource for alternative therapeutic agents, particularly in the event of increased antimicrobial resistance [3, 4]. Its anticancer activity is another extensively researched field, and investigations have indicated selective cytotoxicity against different cancer cell lines through apoptosis induction, mitochondrial dysfunction, and inhibition of metastasis and proliferation. In addition, the plant has anti-inflammatory, antihypertensive, and healing properties, all of which are in consensus with its traditional uses in pain management, hypertension, and skin wounds[1,3,5,6,7]. Considering the range of pharmacological activities seen in various studies, *A. muricata* possesses potential opportunities for the creation of multi-targeted natural drugs. This section investigates and discusses the pharmacological features of *A. muricata* focusing on recent scientific achievements that justify its traditional uses and provide the gateway towards future drug development.

1. Botanical distribution and Phytochemistry

A. muricata is member of annonaceae family, the genus *Annona* which have around species itself is a very frequently used in traditional medicine all around the world. *A. muricata* is member of annonanceae family, it is a tropical, evergreen fruit-bearing tree native to Southeast Asia, South America, and African rainforests. It thrives in warm, humid climates below 1200 meters altitude, with 60-80% relative humidity, 25-28°C temperature, and over 1500 mm annual rainfall. The tree flowers and fruits almost year-round. With obovate shape, leaves of *A. muricata* are glossy, thick and dark green in colour. Flowers are thick and yellow in color with outer petals meeting the edge-to-edge and heart shaped bases; inner petals overlap and are oval-shaped. Fruit is heart-shaped, green, with soft prickles and have acidic pulp with specific aroma[1,2].

Plant contains range of phytochemical and bioactive compounds, and around 212 phytochemicals have been reported, Leaves being the most studied part of plant (**Table 1**). Acetogenins are the dominant bioactive compound, apart from these different alkaloids and phenolics are also reported in different part of plants.

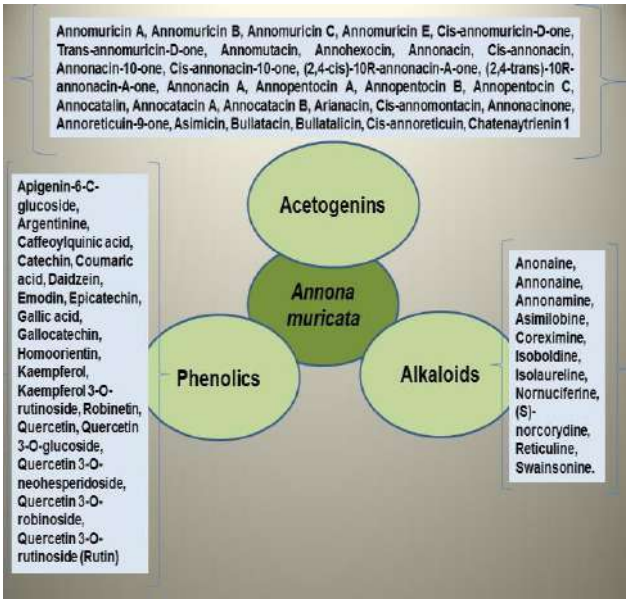

Figure 1: Dominant Bioactive compounds present in *A. muricata*.

Leaves of the plant contains compounds like Annonacin, annonamine, Quercetin, kaemferol, rutin and gallic acid, gallocatechin, while compounds in fruit and pulp are Muricatocin, Coumaric acid, Asimilobine, Caffeoylquinic acid. Pericarp of *A. muricata* fruit is rich in Annomuricin A–C, Annonacin, seeds have compounds like Annonacin-10-one, Annonacin, Bullatacin, Annocatacin A Arianacin, Cis-annomontacin; stems contain swainsonine and coreximine and roots of the plant are rich in solaminmuricadienin and reticuline [3,6,8,9].

UFLC-QTOF-MS of ethanolic extract of leaves revealed presence of phytochemicals like Rutin, loliolide, annopentocin, annomuricin, caffeic acid, asimilobine, kaempferol-3O-rutinoside, xylopine, annohexocinand xi-anomuricine[10]. 17 phytochemicals in leaves of methanolic extract of the plant were identified by Mishra et al (2025) including flavonoids like kaemferol-3-o-rutinoside, quercetin-3-O-D-glucuronide , rutin, apigenin 6,8-di-C-glucoside, eriocitrin, alkaloids like swainsonine, (+)-4'-O-methylcoclaurine, xylopine, and asimilobine along with acetogeninslikemontanacin B/C ,Annomuricin A and annonisin[11].

2. Traditional uses

Ethnobotanical research highlights the wide-ranging use of *Annona muricata* in traditional medicine across tropical regions. The plant of soursop is known for its antibacterial, antifungal, anthelmintic, antihypertensive, anti-inflammatory, and anticancer properties. Traditionally, soursop is also used as an analgesic, antipyretic, and to manage respiratory infections, skin disorders, diabetes, and parasitic diseases[3].

Parts of plant are used in preparing decoction, juice or can be applied topically or can be taken orally. People from countries of south pacific and Indonesia uses leaves of the plant are used in skin ailments while in Mexico, Martinique, Nicaragua and Brazil, it is used for flu, asthma, cold (**Figure 2, Table 1**). Topical application of the leaves is used for relieving pain in Malaysia, it is also used in treating insomnia, diabetes, headaches, and cystitis, diabetes, while decoctions are used as anti-rheumatic neuralgic [1,2]. It is reported that patients also combine the decoction can be taken directly or with warm water, tea, cereals. Fruit juice of the plant is known to be galactagogue and utilized in treating diarrhoea, liver disease, heart related complications and intestinal parasites. Seeds of the plant are reported as effective treatment against parasitic skin disorder and as laxative. Bark of the *A. muricata* is used for diabetes, inflammation, parasite infection, anti-hypertensive, muscle relaxant[3].

People from different region of Africa use parts of *A. muricata* for treating parasite infections, cancer, malaria, stomach related complication and diabetes. People from sub-Saharan Africa utilize the plant in treatment of stomach disorders, diabetes, malaria, cancer and parasitic infection[12]. Seeds are used as anthelmintic and antiparasitic agents while leaves, bark and roots are used for anti-inflammatory, antihypertensive, sedative, antidiabetic, and antispasmodic effects. Leaves are used in conditions such as cystitis, hypertension, headaches, insomnia, liver ailments, and are also used topically for abscesses and skin conditions[1]. In South America, people use soursop fruit juice to manage cardiac and hepatic related problems, and also used as an effective remedy for diarrhea and parasites. The fruit pulp is traditionally consumed to promote lactation, Treat rheumatism, arthritis, fever, neuralgia, dysentery, skin rashes, Serve as an antimalarial, antiparasitic, and anthelmintic agent[2].

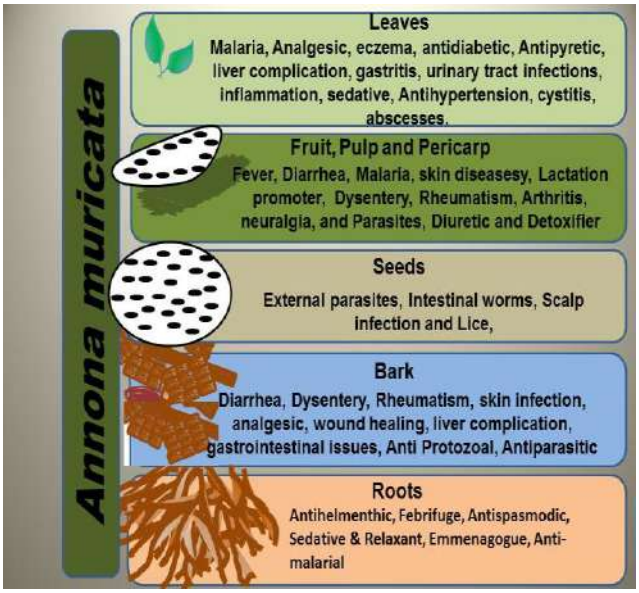

Figure 2: Traditional use of leaves, fruits, pulp, pericarp, seeds, Bark and roots of *A. muricata*.

Table 1. Major compounds present in different parts of *A. muricata* and use of these parts in traditional medicine.

S.No.	Part of plant	Reported phytochemicals	Traditional uses	References
1.	Leaves	Annomuricin (annomuricin A, B, C) Annomuricin E, Cis-annomuricin-D-one, Trans-annomuricin-D-one, Anonainesolamin, Solamin, Muricapentocin ,Annomutacin, Annonacin(2,4-cis)-10R-annonacin-A-one, (2,4-trans)-10R-annonacin-A-one, Annopentocin A, B, C, Annocatalin, Annocatacin B, Annonacinone, Asimicin, Annohexocin, Muricatocin A, B, C ,Muricoreacin, Murihexocin B, C, Annonamine, Asimilobine, Coreximine, Isoboldine, Isolaureline, Nornuciferine, Reticuline, Apigenin-6-C-glucoside, Argentinine, Caffeoylquinic acid Catechin, Annomutacin, Annohexocin, Annonacin, (2,4-cis)-10R-annonacin-A-one, (2,4-trans)-10R-annonacin-A-one, Daidzein, Emodin, Epicatechin, Gallic acid, Gallocatechin, Homoorientin, Kaempferol, Kaempferol 3-O-rutinoside, Robinetin, Quercetin 3-O-glucoside, Quercetin 3-O-neohesperidoside, Quercetin 3-O-robinoside, Quercetin 3-O-rutinoside (Rutin)	Fever, sedative, anti-anxiety, antihypertensive, antispasmodic, wound healing, parasitic infections, liver related complications, gastrointestinal complication, ulcer.	[2,3,11].
2.	Fruits and pulp	Cis-annoreticuin, Muricin J, K, LAnonaine, Annonaine, Nornuciferine, tocotrienols, tocopherol, Coumaric acid Asimilobine, Caffeoylquinic acid, Murihexocin, murihexocin B, C Kaempferol, Kaempferol 3-O-rutinoside	Constipation, dysentery, helminthic infections, ntipyretic, nutritional tonic, skin issues, Digestive disorders antinflammatory, anticancer, antidiabetic, antioxidant.	[3,13,14]
3.	Pericarp	Annomuricin (annomuricin A, B, C) Annonacin Annonacin A	Antimicrobial, antiparasitic, insect repellent, dysentery, diarrhea, skin ailments	[2,3]

4.	Seeds	Annonacin, Annocatacin A Arianacin, Cis-annomontacin, Annonacinone Annoreticuin-9-one, AnnomuricatinA,B,C, Bullatacin, Bullatalicin, Cis-annonacin, Annonacin-10-one, Cis-annonacin-10-one, Cohibin A, B, Cohibin C, D, Corossolone, Muricatacin, Muricatetrocin A, B, Muricenin, Murihexol, MurisolinRolliniastatin 1, Solamin, Squamocin, Cis-squamostatin A, squamostatin D, Xylomaticin	Fumigation, insecticide, Abortifacient, antihelmenthic	[15,16]
5.	Bark , Stem	Coreximine, Coreximine, reticuline, Swainsonine, Atherosperminine, Anomuricine, Anomurine	**Antidiabetic, pain releiver,**antiparasitic, antihelmenthic, anticancer, antimalarial, **arthritis, inflammation,**	[2,17]
6.	Root	Reticuline, Coreximine, Solamin, Cis-reticulatacin, Muridienin 3, 4, Muricadienin, Cohibin A, B, (Sabadelin) chatenaytrienin 1, 2, 3	Antidiabetic, febrifuge, abortefacient, uterotonic, antihelmenthic, antispasmodic.	[1,2,3]

3. Pharmacological properties

Antioxidant activity

Leaves, fruits and bark of *A. muricata* is used to boost general health, aging and against inflammation and fatigue[3]. Richness of plant in bioactive compounds like kaempferol, Quercetin, annonacin, gallic acid, contributes to its antioxidant potential [9].). Methanolic leaf extract of the plant had IC50 of 34.8 µg/mL against 2,2-Diphenyl-1-picrylhydrazyl[9]. Aqueous and 80% methanolic extract of leaves, roots and twigs of the plant had significant antioxidant activity, with leaves having highest against 2,2-Diphenyl-1-picrylhydrazyl[18]. According to some reports methanol and aqueous extracts of root, twigs, fruit pulp and leaf extract of *A. muricata* had reported to have significant antioxidant potential in ABTS and FRAP assays[18,19]. Leaf extract of the plant was able to reduce lipid peroxidation via MDA, while increasing SPD, catalase, GSH and improving pancreatic antioxidant defense[20]. Ethyl acetate extract of the leaves were showing increased levels of antioxidant enzyme in in vivo model[21].

Antidiarrheal Activity

Traditional medicine in countries of West Africa, tropical Asia, Latin American region have utilized fruit pulp and juice of *A. muricata* for gastrointestinal complication including diarrhea. Intestinal complication is treated bark

and fruit[3, 22]. Castor oil induced diarrhea in mice was treated using fruit extract of the plant at 400mg/kg, and it

has been reported to reduce diarrheal frequency and delayed onset of diarrhea[6]. Castor oil induced diarrhea mice when treated with hydroalcoholic extract of *A. muricata* was reported to show good results as standard drug[22].

Antidiabetic Activity

Soursop fruits and all other parts of *A. muricata* have been used for medicinal purpose across the world and reported to possess significant antidiabetic potential. Leaves bark, and roots of the plant is used to prepare decoction and tea. People from Nigeria and Ghana use infusion of leaves to treat diabetes; while in Cameroon and Uganda use various plant parts to manage diabetes and its other symptoms[3]. Several study both invitro and in vivo have been performed to evaluate its antidiabetic potential. Extracts of leaf, pericarp, pulp of the plant was tested against major enzymes in carbohydrate metabolism (alpha amylase and alpha glucosidase); inhibition of both enzyme was observed with IC50 value of 22.3 ± 1.8 µg/mL against alpha glucosidase in case of leaf extract and 35.5 ± 2.4 µg/mL against alpha amylase in case of fruit pericarp extract [23]. Artificially diabetes induced rats with streptozotocin when treated *A. muricata* leaf extract at 100mg/kg dose was able to reduce blood glucose levels, while lowering oxidative stress and increasing body weight [20]. Ethanolic extract of the plant was able to delay glucose peak and enhance glucose clearance[6].

Antimicrobial Activity

Bacteria

A. muricata is reported to be effective against different bacterial strains (Gram positive and Gram negative).. The alkaloids present in the plant can disrupt bacterial membranes. It is reported to have enhanced efficacy against Multidrug resistant strains of *Staphylococcus aureus,*and *Escherichia coli* when combined with antibiotics. The in vitro analysis of leaves has shown significant activity against *Pseudomonas aeruginosa, Staphylococcus aureus, E. coli, Helicobacter pylori*[3,4]. While methanolic fruit extract of the plant has been reported to reduce effects of diarrhoea in mice (*E. coli* induced)[22].

Fungi

Although there are not many reports on antifungal properties of *A. muricata*, *Candida albicans* is known to inhibit by its extract. In a study ethanolic extract of leaves of the plant were able to reduce fungal growth by 58% and cell density by 65% of MDR *C. albicans*[10].. Methanolic extract of leaves were also found effective against C. albicans [11]. Acetogenins isolated from seeds of the plant were able to inhibit growth Candida spp like *C. tropicalis, C. albicans, C.glabrata and C. krusei*[24]. Apart from this soursop is also tested against *Colletotrichum gloeosporioides, Rhizopus stolonifer, Alternaria* and *Cercospora malayensis*[25,26,27].

Protozoa

Traditionally all over the world people have used *A. muricata* for treating protozoal infection, including as an antimalarial medicine. The plant shows broad antiprotozoal efficacy, including against toxoplasmosis, leishmaniasis, malaria, and trypanosomiasis Reports have shown that *A. muricata* indeed have antiprotozoal activity- according to one study the ethanol extract of plant had shown IC50 at concentration of 46.1 µg/ml µg/ml against *Plasmodium falciparum*[28]. Silver nano particle of *A. muricata* was able to counter Dengue, Malaria, and filarial vector[29]. While in case of toxoplasmosis rat model ethanolic leaf extract has reduced parasite load and improved survival [30].

Viruses

Apart from this *A. muricata* also have antiviral properties and the extracts have been reported to be effective against viruses like Herpes simplex virus, SARS-CoV-2, and HIV in different In-vitro, In-vivo and In-silico studies[31]. Acetogenins from the plant like cisannonacin, and muricatocin have been reported to be interacting strongly with corona virus (SARS-CoV-2) protein present in its spike[32], while acidified ethanolic extract of *A. muricata* can decrease viral replication of HSV in a hour[3]. In an In vivo analysis topical application of stem bark extract in HSV infected mice had reduced lesion size and viral titre[7].

Antihypertensive Activity

Different reports have suggested that *A. muricata* contributes to reduce the blood pressure by hindering angiotensin-converting enzyme (ACE)and blocking calcium ion channels, leading to decreased vascular resistance[33]. *A. muricata* with *Persea Americana* was able to reduce blood pressure synergistically [34]. The anti-hypertensive property of the plant is attributed to alkaloids like reticulin and anomurine present in it[4, 33].

Wound Healing

Ethyl acetate extract of the leaf of the plant in 5% and 10% ointment formulations when given to excision wounds in rats was able to increase the wound contraction rate, and was able to reduce levels of malondialdehyde (MDA), which is a indicator of oxidative damage. Apart from this it was able to enhance re-epithelialization and elevate antioxidant enzymes like catalase, SOD and GSH [34]. According to another study methanolic extracts of bark and leaves can enhance epithelial regeneration, shorten epithelialization period, and increase tensile strength of wound tissue[35].

Antiulcer Activity

The bioactive compound present in *A. muricata* like phenolics, alkaloids, tannins have potent gastroprotective activity[9]. Traditionally medicinal system of Africa, Caribbean and South American region utilize decoction and tea made with leaves and bark is used for treating ulcers, gastritis, and indigestion[3]. Hydroalcoholic leaf extract of *A. muricata* was able to reduce ethanol, methanol, or indomethacin induced gastric ulcers at dose of 100-400mg/kg body weight[36]. Ethyl extract of the plant was able to reduce lesion index, MDA, Bax while increasing catalase, SOD, GSH and Hsp 70 expression [37]. *Helicobacter pylori* is a ulcer causing bacteria, methanolic and ethyl acetate leaf extract of the plant has shown strong antibacterial activity against this bacteria with MIC value of 20mg/ml[38].

Anticancer Activity

Table 2: Anticancer activity of extracts/compounds isolated from *A. muricata*

S.no.	Cancer type	Extract/isolated compound	In vitro /In vivo		Mechanism	Reference
			cell line /Model	IC50 (µg/ml)/Dosage (mg/kg)		
1.	**Breast cancer**	• Ethanolic leaf extract • Aqueous leaf extract • Ethanolic leaf extract • Fruit pulp extract	• MCF-7 • MDA-MB-231 • Ehrlich ascites carcinoma (EAC) mice • DMBA-induced breast cancer (rats)	• 14.7 µg/mL • 12.1 µg/mL • 100 mg/kg • 200 mg/kg	Mitochondrial apoptosis, ROS, caspase activation Apoptosis via Baxupregulation and Bcl-2 downregulation. ↓ Tumor size, ↑ life span, ↑ caspase-3 activity ↑ antioxidant enzymes, ↓ lipid peroxidation	3,6,7,41

2.	**Prostate cancer**	• Aqueous leaf extract • AnnopentocinA,B, C,D	PC-3	• 6.6 µg/mL • 1.14, 0.21,0.0.22, 1.32.	Inhibits EGFR/ERK signaling; induces apoptosis	[3,39]
3.	**Pancreatic cancer**	Annomuricin E	CD18/HPAF	1.8 µg/mL	Mitochondrial complex I inhibition	[3,43, 44 45]
4.	**Colon cancer**	• Methanolic fruit extract • Ethyl acetate seed extract	• HT-29 • Colon cancer xenograft (mice)	• 20.6 µg/Ml • 50 mg/kg	DNA fragmentation, caspase-3 activation	[3,43, 44 46,47]
5.	**Lung cancer**	Ethanolic leaf extract	A549	18.6 µg/mL	ROS induction, apoptosis	[3,43, 44 48]
6.	**Liver cancer**	Methanol bark extract	HepG2	27.1 µg/mL	Antiproliferative, DNA fragmentation	[3,43, 44 49]
7.	**Lymphoma**	Methanolic leaf extract	Dalton's lymphoma (mice)	250 mg/kg	↓ Tumor weight, ↑ survival rate	[3,45, 46]

As elaborated in (**Table 2**), several studies (*In vitro* and *In vivo*) on *A. muricata* has shown its potential as an excellent anticancer agent. Ethanolic and ethyl acetate extract of the leaf of the plant can control cell proliferation and was able to induce apoptosis in cell lines (MCF-7 and MDA-MB-231) with IC_{50} value of leaf extract of the plant were able to inhibit proliferation and metastasis in PC-3 and LNCaP cell line of prostate cancer. In HT-29 cell lines methanolic extract of the plant was able to induce apoptosis and cell cycle arrest by activating caspase 3 and DNA fragmentation. Acetogenins are dominant bioactive compounds of *A. muricata*, acetogenins isolated from the plant were able induce cell death while suppressing metastasis by disrupting mitochondrial disruption and affecting cellular ATP production in FG/COLO357 and CD18/HPAF cell lines of pancreatic cancer.

Anti-inflammatory

Potential of soursop as an anti-inflammatory agent have been validated both by its usage in traditional medicine in addition to via different experiments performed *in vitro* and *in vivo* which is directly linked to presence of alkaloids, flavonoids, phenolics and acetogenins present in it. Roots, Leaves and the bark of the plant have been used traditionally for treating fever, swelling, rashes and other skin inflammation along with this it is also used to relieve pain associated with arthritis, muscle inflammation and joints [3]. Nitric oxide (NO) is one of the source of oxidative stress, methanolic extract of leaves were reported to inhibit NO and PGE2 production significantly in LPS-induced RAW 264.7 macrophages having IC50 value of 26.1 µg/mL[3]. According to Gavamukulya et al the plant is able to downregulate pro-inflammatory cytokines (e.g. TNF-alpha, IL6, IL-1Beta) [5]. According to another study aqueous and ethanolic extract of leaves of *A. muricata* at dose of 100-400 mg/kg was able to reduce carrageenan-induced paw edema in dose dependent manner in rats [23]. The plant is also reported to reduce granuloma tissue formation, suppress fibroblast proliferation and exudate its formation[2,3].

Toxicology

A. muricata have been used in curing various diseases traditionally for centuries and its toxicological profile is still needed to be critically investigated. Although it has been scientifically proven that phyto-constituent of the plant and plant extracts do have significant pharmacological potential, still there safety issues using plant as such[3]. The root extracts of the *A. muricata* contain cytotoxins and have neurotoxic effects[2]. The aquous extract of A. muricata at high doses can cause hypoglycemia, hyperlipidemia and kidney damage[46, 47]. Thus, use of the extract is recommended in controlled manner and with proper guidance only. The toxic effects of the plant come from the phytochemical compounds present in it, like acetogenins specifically annonacin is a neurotoxin. High consumption of soursop can cause atypical Parkinsons, causing degeneration of dopaminergic neurons [8]. Seeds of the plant have been reported to have high levels of acetogenins, causing hepatotoxic and neurotoxic effects in rats [49]. Although cytotoxicity of compounds or extracts are important for their anticancerous effect higher doses of A. muricata can lead to non-specific cell killing [2]. Long-term use of seeds, fruit pulp, and root extracts have been recommended to be avoided due to its adverse effects [3].

Conclusion

A. muricata is a valuable and renowned medicinal plant and used widely in traditional medicines around the world for centuries. Tropical and subtropical regions of Africa and Southern America use different parts of plant including leaves, bark, seed, fruits and roots for treating ailments ranging from skin infection, joint pain, rheumatism, and rashes to diabetes, arthritic pain and so on. The pharmacological effects of the plant are dependent on range of bioactive compounds present in it such as acetogenins, flavonoids, Phenolics, alkaloids. The plant of A. muricata tackles wide range of diseases, that includes inflammation, cancer, diabetes, rheumatism, joint pain, gastrointestinal issues, skin problems. Anti-cancerous property of *A. muricata* is particularly noteworthy, the isolated compounds of the plant have displayed low IC50 values against cancer cells both in in vivo and in vitro circumstances, supporting their apoptotic and cytotoxic mechanisms. Apart from this the antidiabetic, antiulcer and antimicrobial activities of the plant have also been validated by various studies. Probably these pharmacological effects were somehow involved inflammatory cytokines, molecular signaling pathways, oxidative stress markers. Although, beyond these therapeutic benefits there are also have negative impacts of extract that is related to presence of some acetogenins (Annonacin). Annonacin is reported to be a neurotoxin that can cause atypical parkinsonism when consumed for prolonged duration.

If we somehow lower the toxicological concern of the plant, while enhancing the potency of the formulation (either extract or isolated compound), it can help in developing a safe and effective therapy against several disease. To do so there is still need of rigorous experimentation and research on the medicinal value, toxicological assessment and standardization around this plant.

Conflict of Interest: None

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References:

1. **Zubaidi S.N., MohdNani H., Ahmad Kamal M.S., Abdul Qayyum T., Maarof S., Afzan A., et al.** *Annona muricata*: Comprehensive review on the ethnomedicinal, phytochemistry, and pharmacological aspects focusing on antidiabetic properties. Life. 13(2) (2023): 353–353.
2. **Mutakin M., Fauziati R., Fadhilah F.N., Zuhrotun A., Amalia R., Hadisaputri Y.E.** Pharmacological activities of soursop (*Annona muricata* Linn.). Molecules. 27(4) (2022): 1201–1201.
3. **Moghadamtousi S.Z., Fadaeinasab M., Nikzad S., Mohan G., Ali H.M., Kadir H.A.** *Annona muricata* (Annonaceae): A review of its traditional uses, isolated acetogenins and biological activities. International Journal of Molecular Sciences. 16(7) (2015): 15625–15658.

4. **Gavamukulya Y., Wamunyokoli F., El-Shemy H.A.** Phytochemical screening, antioxidant activity and in vitro anticancer potential of *Annona muricata* (Graviola). Asian Pacific Journal of Tropical Medicine. 10(7) (2017): 707–715.
5. **Torres M.P., Rachagani S., Guha S., Johansson S.L., Kumar S.** Effects of *Annona muricata* extract in an animal model of breast cancer. Phytomedicine. 19(7) (2012): 598–605.
6. **Gavamukulya Y., Abou-Elella F., Wamunyokoli F., El-Shemy H.A.** Phytochemical screening, antioxidant activity and in vitro anticancer potential of ethanolic and aqueous extracts of *Annona muricata* (Graviola) leaves. Asian Pacific Journal of Tropical Medicine. 7(Suppl 1) (2014): S355–S363.
7. **Padma P.R., et al.** Anticancer activity of *Annona muricata* Linn leaves in 7,12-dimethylbenz(a)anthracene (DMBA) induced breast cancer in rats. International Journal of PharmTech Research. 3(3) (2011): 1065–1070.
8. **Lannuzel A., Höglinger G.U., Champy P., Michel P.P., Hirsch E.C., Ruberg M., et al.** The mitochondrial complex I inhibitor annonacin is toxic to mesencephalic dopaminergic neurons by impairment of energy metabolism. Neuroscience. 112(2) (2002): 349–358.
9. **Baskar R., Rajeswari V., Kumar T.S.** In vitro antioxidant studies in leaves of *Annona* species. Indian Journal of Experimental Biology. 45 (2007): 480–485.
10. **Campos L.M., Lemos A.S.O., Diniz I.O.M., Carvalho L.A., Silva T.P., Dib P.R.B., et al.** Antifungal *Annona muricata* L. (soursop) extract targets the cell envelope of multidrug-resistant Candida albicans. Journal of Ethnopharmacology. 301 (2023): 115856–115856.
11. **Mishra AP, Yalo M, Nambooze J, Pohl CH, Kemp G, Setsiba LK &Matsabisa MG.** Characterization and enhanced antibiofilm activity of *Annona muricata* extract in combination with fluconazole against Candida albicans. Drug Target Insights. 19 (2025): 1–10.
12. **Coria-Téllez AV, Montalvo-Gónzalez E, Yahia EM & Obledo-Vázquez EN.** *Annona muricata*: A comprehensive review on its traditional medicinal uses, phytochemicals, pharmacological activities, mechanisms of action and toxicity. Arabian Journal of Chemistry. 11(5) (2018): 662–691.
13. **Patil HV, Dhankani MA &Dhankani AR.** A review on marvel fruit: *Annona muricata*. Medical Sciences Forum. 21(1) (2023): 26.
14. **Prasad SK, Veeresh PM, Ramesh PS, Natraj SM, Madhunapantula SV &Devegowda D.** Phytochemical fractions from *Annona muricata* seeds and fruit pulp inhibited the growth of breast cancer cells through cell cycle arrest at G0/G1 phase. Journal of Cancer Research and Therapeutics. 16(6) (2020): 1235–1249.
15. **Li CM, Tan NH, Zheng HL, Mu Q, Hao XJ, He YN & Zou J.** Cyclopeptide from the seeds of *Annona muricata*. Phytochemistry. 48(3) (1998): 555–556.
16. **Wélé A, Zhang Y, Caux C, Brouard JP, Pousset JL & Bodo B.**Annomuricatin C, a novel cyclohexapeptide from the seeds of *Annona muricata*. Comptes Rendus Chimie. 7(10–11) (2004): 981–988.
17. **Leboeuf M, Legueut C, Cavé A, Desconclois JF, Forgacs P & JacqueminH.** Alcaloïdes des Annonacées XXIX: Alcaloïdes de l' *Annona muricata* L. Planta Medica. 42(1) (1981): 37–44.
18. **Nam JS, Park SY & Jang HL.** Phenolic compounds in different parts of young *Annona muricata* cultivated in Korea and their antioxidant activity. Applied Biological Chemistry. 60 (2017): 535–543.
19. **Santos IL, Rodrigues AMDC, Amante ER & Silva LHMD.** Soursop (Annona muricata) Properties and Perspectives for Integral Valorization. Foods (Basel). 12(7) (2023): 1448.
20. **Adewole SO & Ojewole JAO.** Protective effects of *Annona muricata* Linn. (Annonaceae) leaf aqueous extract on serum lipid profiles and oxidative stress in hepatocytes of streptozotocin-treated diabetic rats. African Journal of Traditional, Complementary and Alternative Medicines. 6 (2009): 30–37.
21. **Ginting B, Yahya M, Saidi N, Maulana I, Murniana M, Safitri E, Bahi M, Rosiyana Y, Novani H &Milza DNA.** Antioxidant and

cytotoxicity screenings of ethyl acetate extract from *Annona muricata* leaves and its fractions. Journal of Advanced Pharmaceutical Technology and Research. 15(2) (2024): 70–74.

22. **Okeke-Nwolisa BC, Enweani-Nwokelo IB, Unekwe PC &Egbuonu I.** The anti-diarrheal and anti-inflammatory effects of hydroethanol extracts of ripe *Annona muricata* fruit pulp in Wistar rats using curative method. International Journal of Health Sciences (Qassim). 17(3) (2023): 26–32.
23. **Agu KC, Eluehike N & Ofeimun RO.** Possible anti-diabetic potentials of *Annona muricata* (soursop): inhibition of α-amylase and α-glucosidase activities. Clinical Phytoscience. 5 (2019): 21–29.
24. **López-Romero BA, Luna-Bárcenas G, García-MagañaMDL,Anaya-Esparza LM, Zepeda-Vallejo LG & López-García UM.** Extraction of acetogenins using thermosonication-assisted extraction from *Annona muricata* seeds and their antifungal activity. Molecules. 27(18) (2022): 6045.
25. **Rizwana H, Bokahri NA, Alsahli SA, Al Showiman AS, Alzahrani RM &Aldehaish HA.** Postharvest disease management of Alternaria spots on tomato fruit by *Annona muricata* fruit extracts. Saudi Journal of Biological Sciences. 28(4) (2021): 2236–2244.
26. **Riley-Saldaña CA, De-La-Cruz-Chacón I, Cruz-Ortega MDR, Castro-Moreno M & González-Esquinca AR.** Do Colletotrichumgloeosporioides and Rhizopusstolonifer induce alkaloidal and antifungal responses in *Annona muricata* seedlings? ZeitschriftfürNaturforschung C. 78(1–2) (2023): 57–63.
27. **Bolie H, Ndongo B, Ngatsi PZ, Kuate WNT, Dida SLL & EssogueEtame A.** Antifungal activity of *Annona muricata* seed extracts against Cercosporamalayensis, causal agent of cercospora leaf spot disease of okra (Abelmoschusesculentus L.). International Journal of Pathogen Research. 6 (2021): 12–24.
28. **Leesombun A, Boonmasawai S & Nishikawa Y.** Ethanol extracts from Thai plants have anti-plasmodium and anti-toxoplasma activities in vitro. ActaParasitologica. 64(2) (2019): 257–261.
29. **Santhosh SB, Yuvarajan R &Natarajan D.** *Annona muricata* leaf extract-mediated silver nanoparticles synthesis and its larvicidal potential against dengue, malaria and filariasis vector. Parasitology Research. 114(8) (2015): 3087–3096.
30. **Miranda NC, Araujo ECB, Justino AB, et al.** Anti-parasitic activity of *Annona muricata* L. leaf ethanolic extract and its fractions against Toxoplasma gondii in vitro and in vivo. Journal of Ethnopharmacology. 273 (2021): 114019.
31. **Nyirenda J, et al.** Ethnobotanical, phytochemical, and pharmacological potential of *Annona muricata* L.: A comprehensive review. Plants. 2022;11(3):424.
32. **Setiawan T, Darsih C, et al.** In silico investigation of acetogenins from *Annona muricata* as inhibitors of SARS-CoV-2 spike proteins. Molecules. 2021;26(17):5325.
33. **Nwokocha CR, Owu DU, Gordon A, Thaxter K, McCalla G, Ozolua RI, Young L.** Possible mechanisms of action of the hypotensive effect of *Annona muricata* (soursop) in normotensive Sprague–Dawley rats. Pharmaceutical biology. 2012 Nov 1;50(11):1436-41.
34. **Sokpe A, Mensah MLK, Koffuor GA, Thomford KP, Arthur R, Jibira Y, Baah MK, Adedi B, Agbemenyah HY.** Hypotensive and Antihypertensive Properties and Safety for Use of Annona muricata and Perseaamericana and Their Combination Products. Evid Based Complement Alternat Med. 2020 Dec 10;2020:8833828.
35. **Lambebo MK, Kifle ZD, Gurji TB, Yesuf JS.** Evaluation of Wound Healing Activity of Methanolic Crude Extract and Solvent Fractions of the Leaves of VernoniaauriculiferaHiern (Asteraceae) in Mice. J ExpPharmacol. 2021 Jul 23;13:677-692.
36. **Bento EB, Júnior FEB, de Oliveira DR, Fernandes CN, de AraújoDelmondes G, Cesário FRAS, Rodrigues CKS, Sales VDS, de Figueiredo FRSDN, Lemos ICS, Monteiro ÁB, de Menezes IRA, da Costa JGM, Kerntopf MR.** Antiulcerogenic activity of the hydroalcoholic extract of leaves of *Annona muricata* Linnaeus in mice. Saudi J Biol Sci.

2018 May; 25(4):609-621.doi: 10.1016/j.sjbs.2016.01.024. Epub 2016 Jan 21.

37. **Moghadamtousi SZ, Rouhollahi E, Karimian H, Fadaeinasab M, Abdulla MA, Kadir HA.** Gastroprotective activity of *Annona muricata* leaves against ethanol-induced gastric injury in rats via Hsp70/Bax involvement. Drug Des DevelTher. 2014 Oct 28;8:2099-110.
38. **Lee JH, Park JS.** Antibacterial effect of traditional food ingredients for healthcare on Helicobacter pylori. Technology and Health Care. 2019 Sep;27(5):509-18.
39. **Yang C, Gundala SR, Mukkavilli R, Vangala S, Reid MD, Aneja R.** Synergistic interactions among phytochemicals from graviola (*Annona muricata*) leaves in suppressing prostate cancer cell proliferation and metastasis. Carcinogenesis. 2015;36(6):656–665.
40. **Oberlies NH, Chang CJ, McLaughlin JL.** Structure–activity relationships of diverse annonaceousacetogenins against multidrug resistant human mammary adenocarcinoma (MCF-7/Adr) cells. J Med Chem. 1997;40(5):1058–1066.
41. **Naik AV, Dessai SN, Sellappan K.** Antitumour activity of *Annona muricata* L. leaf methanol extracts against Ehrlich Ascites Carcinoma and Dalton's Lymphoma Ascites mediated tumours in Swiss albino mice. Libyan Journal of Medicine. 2021 Oct 7;16(1).
42. **Pieme CA, Penlap VB, Nkegoum B, Tazemda G, Ngogang J, GonsuKamga H.** In vitro cytotoxicity and antioxidant activity of *Annona muricata* (soursop) fruit extracts on human cancer cell lines. BMC Complement Altern Med. 2014;14:516.
43. **Zeng L., Wu F. E., Oberlies N. H., McLaughlin J. L., Sastrodihajo S.** Five new monotetrahydrofuran ring acetogenins from the leaves of *Annona muricata*. J. Nat. Prod. 1996. 59, 1035–1042.
44. E**lisya Y., Kardono L. B. S., Simanjuntak P.** Tablet formulation of the ethyl acetate soluble extract of soursop (*Annona muricata* L). leaves. AJAS. 2014; 2 (3), 323–329.
45. **Paul J, Haldar PK, Ghosh AK.** Evaluation of antitumor activity of *Annona muricata* Linn. extract on Ehrlich ascites carcinoma treated mice. Asian Pac J Trop Biomed. 2011;1(1):8–12
46. **Lannuzel A, Höglinger GU, Champy P, Michel PP, Hirsch EC, Ruberg M, et al.** The mitochondrial complex I inhibitor annonacin is toxic to mesencephalic dopaminergic neurons by impairment of energy metabolism. Neuroscience. 2002;112(2):349–358.
47. **Badrie N, Schauss AG.** Soursop (*Annona muricata* L.): composition, nutritional value, medicinal uses, and toxicology. InBioactive foods in promoting health 2010 Jan 1 (pp. 621-643). Academic Press.
48. **Escobar-Khondiker, M.; Höllerhage, M.; Muriel, M.P.; Champy, P.; Bach, A.; Depienne, C.; Respondek, G.; Yamada, E.S.; Lannuzel, A.; Yagi, T.; et al.** Annonacin, a Natural Mitochondrial Complex I Inhibitor, Causes Tau Pathology in Cultured Neurons. J. Neurosci. 2007, 27, 7827–7837.
49. **Arthur, F.; Woode, E.; Terlabi, E.L. C.** Evaluation of Acute and Subchronic Toxicity of *Annona muricata* (Linn.) Aqueous Extract in Animals. Eur. J. Exp. Biol. 2011, 1, 115–124.

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वाराणसी शहर के परिप्रेक्ष्य में वरुणा नदी

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सारांश:

वरुणा नदी, गंगा नदी की एक प्रमुख सहायक नदी है, जो उत्तर प्रदेश के वाराणसी शहर में भौगोलिक और सांस्कृतिक दृष्टि से महत्वपूर्ण भूमिका निभाती है। यह नदी न केवल पानी का स्रोत है, बल्कि वाराणसी शहर के धार्मिक और ऐतिहासिक धरोहर का अभिन्न हिस्सा भी है। हालांकि, शहरीकरण और औद्योगिक के परिणामस्वरूप इस नदी के जल की गुणवत्ता में गिरावट,अत्यधिक प्रदूषण और पर्यावरणीय जैसी समस्याएं उत्पन्न हुई हैं, जिससे नदी की पारिस्थितिकी तंत्र पर गंभीर संकट मंडरा रहा है। इस शोध पत्र में वाराणसी के शहरी जनसंख्या के संदर्भ में वरुणा नदी के भौगोलिक, सांस्कृतिक और पर्यावरणीय महत्व का विश्लेषण किया गया है। इसमें नदी के धार्मिक, सांस्कृतिक और ऐतिहासिक पहलुओं पर भी चर्चा की गई है, साथ ही शहरी विकास द्वारा उत्पन्न होने वाली समस्याओं पर प्रकाश डाला गया है। इसके अतिरिक्त, नदी के संरक्षण और पुनरुद्धार के लिए उठाए गए प्रयासों की समीक्षा की गई है, जिनमें सरकारी योजनाएं और स्थानीय समुदायों की भागीदारी शामिल हैं। यह अध्ययन यह सिद्ध करता है कि नदी के पुनरुद्धार के लिए समग्र जल प्रबंधन, सतत शहरी नियोजन और जन सहभागिता की आवश्यकता है, ताकि नदी को फिर से उसकी पुरानी स्थिति में बहाल किया जा सके और शहर के पारिस्थितिकी तंत्र तथा सांस्कृतिक धरोहर को संरक्षित किया जा सके।

मुख्य शब्द : वरुणा नदी, शहरीकरण, प्रदूषण, सांस्कृतिक धरोहर, नदी संरक्षण, पर्यावरणीय चुनौतियां।

परिचय:

वाराणसी का शहरीकरण मुख्य रूप से बढ़ती जनसंख्या, भूमि उपयोग में बदलाव, और उद्योगों की स्थापना के कारण हुआ है, जिससे नदी के जलग्रहण क्षेत्र में काफी परिवर्तन हुआ है। मिश्रा (2011) के अनुसार, शहरीकरण के कारण वाराणसी जल निकासी प्रणालियों की विफलता, अव्यवस्थित सीवेज और कचरे का जमा होना नदी के जल प्रदूषण का मुख्य कारण है।

इस प्रदूषण से नदी के पारिस्थितिकी तंत्र पर भारी असर पड़ा है, जैसे कि जल की गुणवत्ता में गिरावट, जैव-विविधता का संकट और स्थानीय समुदायों की आजीविका में संकट, इसके अतिरिक्त, शहरीकरण ने नदी के किनारे अवैध निर्माणों और भवनों के रूप में भू-उपयोग में बदलाव किया है, जिससे नदी का प्रवाह बाधित हुआ है। शहरी विकास के साथ-साथ सीवेज और औद्योगिक अपशिष्टों का नदी में गिरना भी जल को प्रदूषित कर रहा है, जिससे नदी का पारिस्थितिकी तंत्र कमजोर हो गया है। कुमार (2013) ने इस पर टिप्पणी करते हुए कहा कि, वाराणसी के शहरीकरण ने नदी के पारिस्थितिकी तंत्र में अप्रत्याशित परिवर्तन किए हैं, जिससे जल प्रदूषण और जल स्रोतों की कमी जैसे गंभीर परिणाम सामने आए हैं। इसके परिणामस्वरूप, न केवल वाराणसी की सामाजिक-आर्थिक संरचना पर प्रतिकूल असर पड़ा है, बल्कि नदी से जुड़े समुदायों की पारंपरिक जीवनशैली भी प्रभावित हुई है। शहरीकरण ने नदी के आस-पास रहने वाले लोगों के लिए जल की गुणवत्ता, जल आपूर्ति और जीवनयापन के साधनों को कठिन बना दिया है, जिससे उनके लिए यह नदी पहले जैसी जीवन-रेखा नहीं रही। इसके बावजूद, सरकार और विभिन्न पर्यावरणीय संगठनों द्वारा नदी के संरक्षण के लिए कदम उठाए गए हैं, जैसे कि स्वच्छ गंगा मिशन और राष्ट्रीय नदी संरक्षण योजना, जो प्रदूषण को कम करने और नदी के पारिस्थितिकी तंत्र को पुनर्जीवित करने के उद्देश्य से चलाए जा रहे हैं (भारत सरकार, 2015)। हालांकि, इन प्रयासों के बावजूद, शहरीकरण के बढ़ते प्रभाव और जनसंख्या वृद्धि के कारण नदी के संरक्षण में चुनौतियाँ बनी हुई हैं और इन समस्याओं का समाधान एक बहुआयामी दृष्टिकोण से ही संभव है। इस शोध का उद्देश्य वरुणा नदी पर शहरीकरण के प्रभावों का विश्लेषण करना और इसके समाधान के लिए सटीक नीति निर्माण की दिशा में सुझाव देना है।

अध्ययन क्षेत्र वाराणसी:

वाराणसी, जिसे काशी भी कहा जाता है, उत्तर प्रदेश राज्य का एक ऐतिहासिक और धार्मिक दृष्टि से अत्यधिक महत्वपूर्ण शहर है,जो गंगा नदी के किनारे पर स्थित है। वाराणसी का विस्तार 25°11′N से 25°23′N अक्षांश (Latitude) के बीच और 82°47′E से 83°03′E देशांतर (Longitude) (चित्र.1)के बीच है; जो इसे भारत के मध्य-पूर्वी हिस्से में एक प्रमुख शहरी केंद्र बनाता है। गंगा नदी के किनारे बसा हुआ यह शहर अपने अद्वितीय भौगोलिक स्थान के लिए प्रसिद्ध है। वाराणसी में गंगा नदी और अस्सी नदी के अलावा, यहाँ की एक और महत्वपूर्ण नदी, वरुणा नदी है , जो गंगा नदी के तट से कुछ किलोमीटर दूर उत्तर-पूर्व में बहती है, इस क्षेत्र के भौगोलिक संरचना का अहम हिस्सा है। इस नदी का नाम भी शहर के नाम से जुड़ा हुआ है और इसे धार्मिक दृष्टि से पवित्र माना जाता है। वरुणा और गंगा नदी के संगम स्थल के निकट स्थित

होने के कारण यह स्थान धार्मिक दृष्टि से अत्यधिक महत्व रखता है। वरुणा नदी, गंगा के जल में अतिरिक्त पवित्रता का संचार करती है और शहर के इस हिस्से को एक विशेष धार्मिक महत्ता प्रदान करती है।

वरुणा नदी:

वरुणा नदी गंगा की एक प्रमुख सहायक नदी है जो वाराणसी शहर की पश्चिमी सीमा से बहती है। नदी का भौगोलिक और पर्यावरणीय विश्लेषण वाराणसी उपमहाद्वीप की जलवायु और भूगोल को समझने के लिए महत्वपूर्ण है। वरुणा नदी 25°27' उत्तरी अक्षांश (Latitude) और 82°18' पूर्वी देशांतर (Longitude) से शुरू होती है और 25°45' उत्तरी अक्षांश और 82°3' पूर्वी देशांतर तक विस्तारित होती है। यह नदी पूर्वी और दक्षिण-पूर्वी दिशा में बहती है जो इलाहाबाद के फूलपुर तहसील से निकलकर वाराणसी के पास गंगा नदी में मिल जाती है (चौरसिया एट अल., 2013)। वरुणा नदी का स्रोत बसुही और मोरवा नदियों (चित्र.2), जलाशयों, तालाबों और सिंचाई नालों के अधिक बहाव से जुड़ा हुआ है। यह नदी लगभग 70 किलोमीटर तक बहती है और फिर मोरावा और बसुही नदियों से मिलती है। इसके बाद यह नदी वाराणसी शहर से होते हुए गंगा नदी से मिल जाती है, विशेष रूप से सराय मोहन के पास (वाराणसी नगर निगम)। नदी का यह मार्ग न केवल भौगोलिक दृष्टि से महत्वपूर्ण है, बल्कि यह क्षेत्रीय जलवायु, पारिस्थितिकी और मानव सभ्यता के लिए भी एक आवश्यक स्रोत रहा है। वरुणा नदी के जलग्रहण क्षेत्र में विभिन्न जलस्रोत शामिल हैं, जैसे झरने, नदियाँ और तालाब, जो इसके जल प्रवाह को प्रभावित करते हैं। इस नदी का पारिस्थितिकी तंत्र जैव विविधता से समृद्ध है और यह क्षेत्रीय पारिस्थितिकी को संतुलित करने में एक महत्वपूर्ण भूमिका निभाता है (शर्मा एट अल.,2016)। हालांकि, शहरीकरण और औद्योगिक के कारण नदी का जल प्रदूषण बढ़ गया है और इससे नदी के पारिस्थितिकी तंत्र पर नकारात्मक प्रभाव पड़ा है (चौरसिया एट अल., 2013)। प्रदूषण के कारण नदी की जल गुणवत्ता में गिरावट आई है, और इसके जल का उपयोग कृषि और पेयजल के लिए संकटपूर्ण हो गया है (शर्मा एट अल.,2016)।

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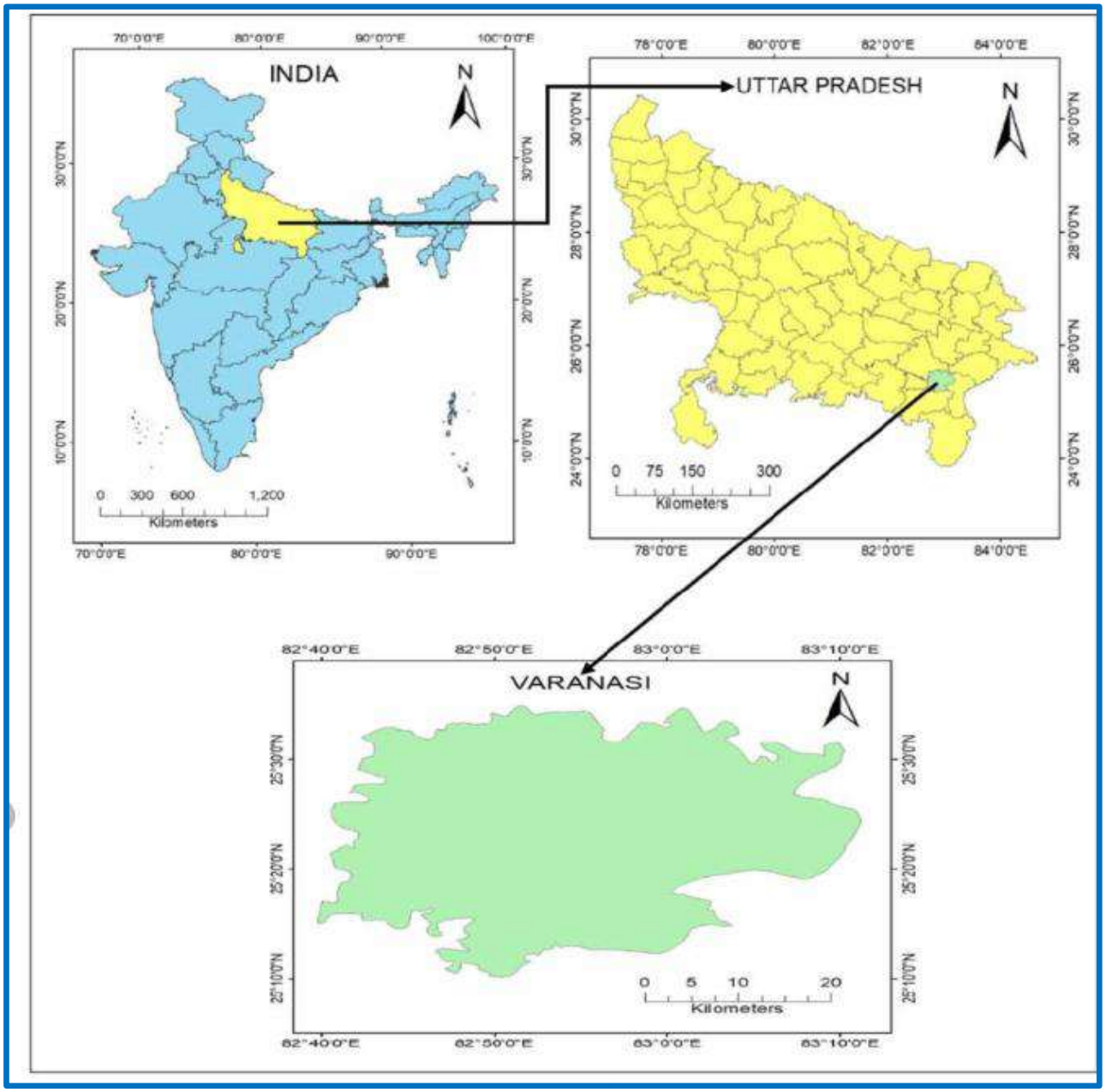
चित्र 1: वाराणसी का भौगोलिक मानचित्र



स्रोत: अग्रवाल एट अल. (2023)

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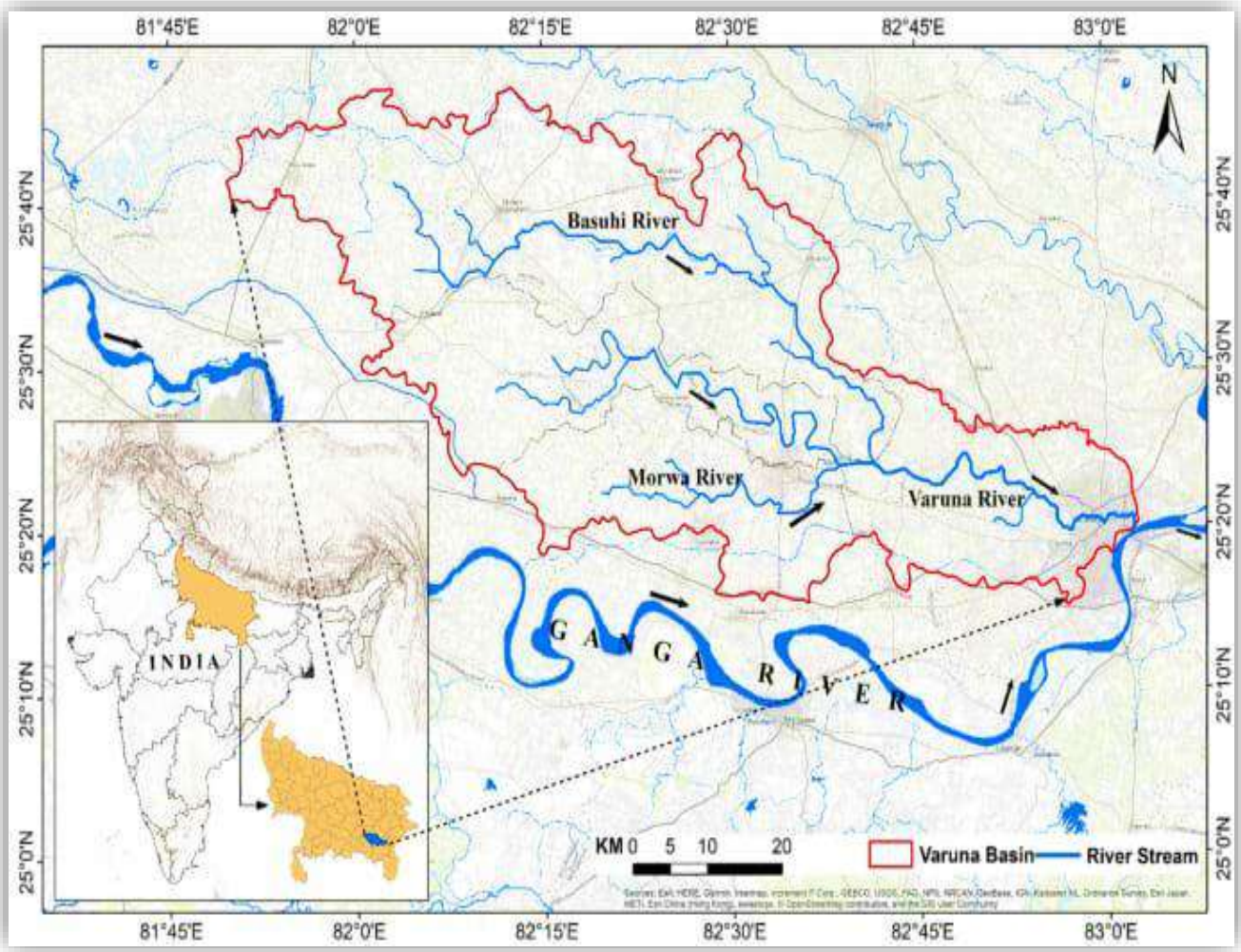
चित्र 2: वरुणा नदी क्षेत्र का भौगोलिक मानचित्र



स्रोत: चौबे एट अल. (2019)

शहरी जनसंख्या के संदर्भ में वरुणा नदी का भौगोलिक पर्यावरणीय महत्व:

वाराणसी, जो भारतीय उपमहाद्वीप के प्राचीनतम और सांस्कृतिक रूप से समृद्ध शहरों में से एक है, वरुणा और गंगा नदियों के संगम पर स्थित है। यहां की भौगोलिक स्थिति और पर्यावरणीय संसाधन, विशेष रूप से वरुणा नदी, इस शहर के जीवन और संस्कृति के लिए अत्यधिक महत्वपूर्ण हैं। यह शहर के उत्तर-पूर्व में बहती है, जहां इसकी उपस्थिति न केवल पानी की आपूर्ति में सहायक होती है, बल्कि यह पर्यावरणीय रूप से भी महत्वपूर्ण है। प्रकाश (2005) के अनुसार, वरुणा नदी वाराणसी के जल आपूर्ति तंत्र का एक अभिन्न हिस्सा है और यहां के पारिस्थितिकी तंत्र को बनाए रखने में महत्वपूर्ण भूमिका निभाती है। यह नदी शहरी क्षेत्रों के लिए जल आपूर्ति के स्रोत के रूप में कार्य करती है, साथ ही इसके जल में विभिन्न जल-जीवों और वनस्पतियों का बसेरा है, जो स्थानीय जैव विविधता को बनाए रखने में सहायक हैं। वरुणा नदी का भौगोलिक

महत्व यहाँ के स्थानीय जलवायु को प्रभावित करने में भी महत्वपूर्ण भूमिका निभाती है। शर्मा (2016)ने इस संदर्भ में कहा कि, वरुणा नदी की उपस्थिति ने वाराणसी के जलवायु को बनाए रखने में मदद की है, और इसके जल प्रवाह ने आस-पास के क्षेत्रों में आर्द्रता और तापमान को संतुलित किया है। यह नदी गर्मी के मौसम में आस-पास के क्षेत्रों में ठंडक बनाए रखने के साथ-साथ वर्षा के मौसम में जल वृद्धि भी प्रदान करती है, जो कृषि और अन्य जल उपयोग के लिए महत्वपूर्ण है । नदी की उपस्थिति ने वाराणसी के पारिस्थितिकी तंत्र को लाभ पहुंचाया है, क्योंकि यह जैव विविधता को बनाए रखने में मदद करती है, विशेष रूप से जल-जीवों और वनस्पतियों के लिए उपयुक्त आवास प्रदान करती है। नदी का पर्यावरणीय महत्व इसके जैव विविधता में भी परिलक्षित होता है। राजू (2009) ने बताया, वरुणा नदी विभिन्न प्रकार के जल-जीवों और वनस्पतियों का घर है, जो इसके पारिस्थितिकी तंत्र के स्वस्थ होने का संकेत देते हैं। यह नदी मछलियों, जल पक्षियों और अन्य जल-जीवों के लिए महत्वपूर्ण है, जो नदी के पर्यावरणीय संतुलन को बनाए रखने में मदद करते हैं। इसके अलावा, नदी के किनारे उगने वाली वनस्पतियाँ स्थानीय पारिस्थितिकी के लिए आवश्यक हैं, क्योंकि ये मिट्टी के कटाव को रोकने में मदद करती हैं और जलवायु में सुधार करती हैं।

शहरीकरण और जनसंख्या वृद्धि:

वाराणसी में शहरीकरण और जनसंख्या वृद्धि के आंकड़े एक दिलचस्प और महत्वपूर्ण प्रवृत्ति को दर्शाते हैं, जो न केवल शहर की ऐतिहासिक और सांस्कृतिक महत्वपूर्णता से जुड़ी है, बल्कि इसके आर्थिक और सामाजिक विकास के संकेत भी देते हैं। 1901 में वाराणसी की कुल जनसंख्या 12,88,891 थी, जिसमें से शहरी जनसंख्या 2,55,086 थी, और इस दौरान शहरीकरण की दर 0% (तालिका :1)थी। 1911 में शहरी जनसंख्या में 3.6% की गिरावट देखी गई, जो एक अस्थायी घटाव था, लेकिन 1921 में शहरी जनसंख्या में 3.2% की वृद्धि हुई, जो इस क्षेत्र में शहरीकरण के बढ़ने का संकेत था। 1931 में शहरी जनसंख्या की वृद्धि दर 10.8% थी, जो इस समय के दौरान औद्योगिक और शहरों में बुनियादी ढांचे के विकास का संकेत देती है। इसके बाद 1941 और 1951 के दशक में शहरी जनसंख्या में क्रमशः 19.8% और 39.8% की वृद्धि हुई, जो इस समय में वाराणसी में शहरीकरण की तीव्र दर को दर्शाता है, जब उद्योग और व्यापार के अवसर बढ़े और शहर ने अधिक ग्रामीण जनसंख्या को आकर्षित किया। 1961 से 1971 के बीच शहरी जनसंख्या की वृद्धि दर में कुछ कमी आई, लेकिन 1981 में शहरी जनसंख्या में 38.8% की वृद्धि दर्ज की गई, जो शहर के तेजी से शहरीकरण का संकेत था। 1991 में शहरी जनसंख्या वृद्धि दर घटकर 18.9% हो गई, और 2001 में यह 18.2% तक कम हो गई, जो शहर के शहरीकरण में स्थिरता और आर्थिक संरचना में बदलाव को दर्शाता है।

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2011 में शहरी जनसंख्या में फिर से 27.8% की वृद्धि हुई, जो शहरीकरण के नई दिशा में बढ़ने का संकेत देती है। कुल मिलाकर, 1901 से 2011 तक वाराणसी की कुल जनसंख्या में 185% और शहरी जनसंख्या में 523% की वृद्धि हुई, जो शहरीकरण और विकास की महत्वपूर्ण दिशा को स्पष्ट करता है। यह वृद्धि न केवल शहर के सामाजिक और आर्थिक परिवर्तनों का संकेत है, बल्कि यह इस बात की भी पुष्टि करती है कि वाराणसी में रोजगार, शिक्षा, स्वास्थ्य सेवाओं और बेहतर बुनियादी ढांचे के कारण शहरीकरण की गति तेज हुई है।

तालिका 1: वाराणसी जिले में दशकीय शहरी जनसंख्या वृद्धि (1901-2011)

वर्ष	जनसंख्या		दशकीय वृद्धि (%)	
	कुल	शहरी	कुल	शहरी
1901	1288891	255086	0	0
1911	1296567	218012	0.6	-3.6
1921	1316977	224913	1.6	3.2
1931	1408845	248043	7.1	10.8
1941	1671388	297237	18.6	19.8
1951	1980090	415547	18.5	39.8
1961	2364874	553146	19.4	33.1
1971	2852459	716774	20.6	29.6
1981	3701006	994823	29.7	38.8
1991	2508110	1057972	2.2	18.9
2001	3138671	1250039	25.1	18.2
2011	3676841	1597051	17.1	27.8

स्रोत: जिला सांख्यिकी हैंडबुक और भारतीय जनगणना (1901-11)

वरुणा नदी पर शहरीकरण का प्रभाव:

शहरीकरण के कारण वरुणा नदी में कई समस्याएँ उत्पन्न हुई हैं,बढ़ती जनसंख्या और अव्यवस्थित शहरीकरण के कारण नदी के किनारे अवैध निर्माण, अपशिष्ट प्रवाह, और जल निकासी के मुद्दे गंभीर हो गए हैं, जैसे-जैसे शहरीकरण और औद्योगीकरण बढ़े हैं, इस नदी के स्वास्थ्य पर नकारात्मक प्रभाव पड़ा है। वरुणा नदी के किनारे बढ़ती जनसंख्या, अव्यवस्थित शहरीकरण, औद्योगिक और कृषि अपशिष्टों के कारण प्रदूषण की समस्या गंभीर रूप ले चुकी है। शर्मा (2016) ने उल्लेख किया है कि , वाराणसी में बढ़ती जनसंख्या और अव्यवस्थित शहरीकरण के कारण वरुणा नदी में प्रदूषण की दर में लगातार वृद्धि हो रही है। इसके कारण नदी का जल उपयोगिता घट रही है और यह पर्यावरणीय संकट पैदा कर रहा है। शहरी क्षेत्रो में उद्योग के चलते भारी मात्रा में औद्योगिक अपशिष्ट नदी में मिल रहा है, जिससे पानी की गुणवत्ता और खराब हो रही है, इसके परिणामस्वरूप नदी का जल न केवल पीने योग्य नहीं रहा है, बल्कि यह स्थानीय पारिस्थितिकी तंत्र के लिए भी खतरे का कारण बन गया है । वरुणा नदी में पानी की गुणवत्ता में गिरावट मुख्यतः सीवेज, औद्योगिक अपशिष्ट, और कृषि रसायनों के कारण हुई है, जिससे नदी में जल प्रदूषण का स्तर अत्यधिक बढ़ गया है (चौरसिया एट अल.,2013)। शहरी जनसंख्या के साथ बढ़ते अपशिष्ट जल, सीवेज और औद्योगिक प्रदूषण का प्रभाव नदी की जल गुणवत्ता पर नकारात्मक रूप से पड़ रहा है,जिसके परिणामस्वरूप नदी की पारिस्थितिकी तंत्र की असंतुलन की स्थिति उत्पन्न हो रही है और यह पानी के जीवों की प्रजातियों को नष्ट करने का कारण बनता है । इसके अतिरिक्त, नदी के किनारे अवैध निर्माणों का बढ़ना न केवल नदी के प्राकृतिक प्रवाह को बाधित करता है, कृषि अपशिष्टों का नदी में प्रवाह भी प्रदूषण के एक बड़े कारण के रूप में सामने आया है । जब किसानों द्वारा इस्तेमाल किए गए रासायनिक उर्वरक, कीटनाशक, और अन्य रसायन वर्षा के साथ नदी में बह जाते हैं, तो नदी में घुलनशील रसायनों की मात्रा में वृद्धि होती है तथा कृषि अपशिष्टों के कारण नदी के जल में रासायनिक प्रदूषण अत्यधिक बढ़ जाता है, जिससे जल की गुणवत्ता में गिरावट आती है और इसके पारिस्थितिकी तंत्र पर प्रतिकूल प्रभाव पड़ता है; इन अपशिष्टों के कारण नदी के जल में ऑक्सीजन की कमी हो जाती है, जिससे जल-जीवों की मृत्यु होती है और जैव विविधता पर भी नकारात्मक असर पड़ता है इसके साथ ही, नदी के जल में घुली हुई घातक रासायनिक तत्वों के कारण मानव स्वास्थ्य पर भी नकारात्मक असर पड़ता है, खासकर उन लोगों पर जो नदी के पानी का उपयोग अपने घरेलू कार्यों के लिए करते हैं (पाण्डेय एट अल,2005)। शहरीकरण और औद्योगीकरण के कारण वरुणा नदी के जल में वृद्धि हो रही प्रदूषण की दर से स्वास्थ्य संबंधी समस्याएँ भी बढ़ी हैं । नदी के किनारे रहने वाले लोग प्रदूषित जल का उपयोग करने के कारण जलजनित रोगों से जूझ रहे हैं, हैजा, दस्त, मलेरिया और डेंगू जैसे रोगों के प्रसार में

वृद्धि हो रही है। वाराणसी प्रदूषण नियंत्रण बोर्ड के अनुसार , नदी के पानी में बढ़ते प्रदूषण के कारण वाराणसी के स्थानीय समुदायों में जलजनित बीमारियाँ आम हो गई हैं; इस कारण स्थानीय स्वास्थ्य सेवाओं पर भी अतिरिक्त दबाव पड़ा है और चिकित्सा सुविधाओं की कमी महसूस हो रही है। यह स्थिति न केवल स्वास्थ्य संकट को जन्म दे रही है, बल्कि यह शहरी और ग्रामीण क्षेत्रों के बीच असमान स्वास्थ्य सुविधाओं के कारण सामाजिक असंतुलन का कारण भी बन रही है।

वरुणा नदी के संरक्षण और पुनरुद्धार के लिए उठाए गए प्रयासों की समीक्षा:

शहरीकरण, प्रदूषण, और अव्यवस्थित जल निकासी के कारण यह नदी गंभीर पर्यावरणीय संकट का सामना कर रही है। इसके जल में प्रदूषण, अवैध निर्माणों और औद्योगिक अपशिष्टों के प्रवाह ने नदी के पारिस्थितिकी तंत्र को नष्ट कर दिया है, इस स्थिति को सुधारने के लिए विभिन्न सरकारी योजनाओं और स्थानीय समुदायों की भागीदारी के माध्यम से कई प्रयास किए गए हैं।

सरकारी योजनाएँ और नीतियाँ:

वरुणा नदी के संरक्षण और पुनरुद्धार के लिए विभिन्न सरकारी योजनाओं का आयोजन किया गया है, केंद्रीय और राज्य सरकारों ने नदी के जल की गुणवत्ता में सुधार लाने के लिए कई कदम उठाए हैं। गंगा पुनरुद्धार योजना के अंतर्गत वरुणा नदी के प्रदूषण को कम करने के लिए कई उपाय किए गए हैं, जिनमें नदी के किनारे अवैध निर्माणों को हटाना और जल निकासी की व्यवस्था को सुधारना शामिल है। इसके अंतर्गत जल शुद्धिकरण संयंत्रों की स्थापना, प्रदूषण नियंत्रण और जल पुनर्चक्रण के उपाय किए गए हैं। इसके साथ ही, नदी के आस-पास के क्षेत्रों में हरित पट्टी (ग्रीन बेल्ट) बनाने और नदी के किनारे सफाई अभियान चलाने के प्रयास भी किए गए हैं। इसके अतिरिक्त, भारत सरकार द्वारा राष्ट्रीय नदी संरक्षण योजना (NRCP) के तहत वरुणा नदी के लिए विशेष योजनाएँ बनाई गई हैं, जिसमें नदी की जल गुणवत्ता में सुधार के लिए शोधन संयंत्रों की स्थापना और प्रदूषण नियंत्रण उपकरणों का विकास शामिल है, इसके अतिरिक्त, स्वच्छ गंगा मिशन (Namami Gange Mission) के तहत वरुणा नदी पर भी ध्यान केंद्रित किया गया है, ताकि गंगा नदी से जुड़ी हुई नदियों के प्रदूषण को नियंत्रित किया जा सके। इस मिशन के अंतर्गत नदी के किनारे बसे क्षेत्रों में जल शोधन संयंत्र, सीवेज उपचार, और ठोस कचरे के निस्तारण की योजनाओं का कार्यान्वयन किया गया है। वरुणा नदी के संरक्षण हेतु किए गए प्रयासों में जलवायु परिवर्तन के प्रभावों को ध्यान में रखते हुए जलवायु अनुकूलन योजना तैयार की गई है, ताकि नदी के जल प्रवाह में असंतुलन को नियंत्रित किया जा सके।

भारत सरकार ने नदियों के जलग्रहण क्षेत्र में वृक्षारोपण अभियान भी शुरू किया है, ताकि जल धारण क्षमता बढ़ाई जा सके और नदी के प्रदूषण को कम किया जा सके (शर्मा एट अल., 2016)। इसके साथ ही, वाराणसी नगर निगम द्वारा शहर में जल पुनर्चक्रण परियोजनाएँ भी शुरू की गई हैं, जो नदी के जल स्रोतों को पुनर्जीवित करने का प्रयास करती हैं। वरुणा नदी पर बढ़ते शहरीकरण के प्रभाव को कम करने के लिए शहरी नियोजन में सुधार की दिशा में कदम उठाए गए हैं, जिसमें नदी के किनारे अनियंत्रित निर्माण गतिविधियों पर अंकुश लगाने के लिए विशेष निर्देश दिए गए हैं। भारतीय नदियों के पुनरुद्धार के लिए जल संसाधन मंत्रालय ने विशेष रूप से पर्यावरणीय दृष्टिकोण से सख्त नीतियाँ बनाई हैं, जो नदी संरक्षण के लिए दीर्घकालिक योजनाओं की दिशा में काम करती हैं।

स्थानीय समुदायों की भागीदारी:

वरुणा नदी के संरक्षण और पुनरुद्धार में स्थानीय समुदायों की भागीदारी महत्वपूर्ण रही है, नदी के किनारे रहने वाले स्थानीय लोग और विभिन्न सामाजिक संगठन नदी की सफाई और संरक्षण में सक्रिय रूप से शामिल हुए हैं। स्थानीय समुदायों की सक्रिय भागीदारी से कई सफाई अभियान चलाए गए हैं, जिनके माध्यम से नदी से कचरा और प्रदूषक हटाए गए हैं। इसके अलावा, सामाजिक संगठनों ने पर्यावरणीय जागरूकता अभियानों के जरिए नदी के महत्व के बारे में स्थानीय लोगों को बताया गया है और प्रदूषण नियंत्रण के उपायों को अपनाने के लिए प्रेरित किया है। स्थानीय लोगों ने अपने स्तर पर पानी की गुणवत्ता में सुधार लाने के लिए प्रयास किए हैं। उदाहरण के लिए, स्थानीय समुदायों ने जल पुनर्चक्रण तकनीकों को अपनाया है, जिससे नदी में गिरने वाले प्रदूषित जल की मात्रा को कम किया जा रहा है। इसके तहत, कई घरों में जल पुनः उपयोग की तकनीकें जैसे वर्षा जल संचयन और जल छानने के उपकरणों का उपयोग किया जा रहा है, जिससे नदी में कम प्रदूषित जल जाता है और जल की गुणवत्ता में सुधार होता है। इसके अतिरिक्त, समुदाय के लोग अब नदी के आस-पास अवैध निर्माणों के खिलाफ आवाज उठाते हैं और स्थानीय अधिकारियों से इस समस्या के समाधान की मांग करते हैं। स्थानीय समुदायों का सक्रिय योगदान इस क्षेत्र में प्रदूषण के प्रति जागरूकता बढ़ाने में सहायक रहा है। हालांकि, सामुदायिक भागीदारी में चुनौतियाँ भी हैं, जैसे कि सूचना की कमी और स्थानीय लोगों का प्रदूषण के प्रभावों के बारे में अपर्याप्त ज्ञान। स्थानीय समुदायों के बीच पर्यावरणीय शिक्षा और प्रशिक्षण कार्यक्रमों का अभाव है, जो प्रदूषण नियंत्रण के उपायों को सही तरीके से अपनाने में बाधक बनते हैं।

नदी के संरक्षण के लिए भविष्य की दिशा:

वरुणा नदी के संरक्षण और पुनरुद्धार के लिए उठाए गए कदमों की सफलता में कई कारक अहम हैं। सबसे पहले, सरकार को चाहिए कि वह नदी के प्रदूषण पर नियंत्रण के लिए ठोस और दीर्घकालिक नीतियाँ तैयार करे और उनके अमल में तेजी लाए। इसके साथ ही, औद्योगिक और कृषि अपशिष्टों के निस्तारण के लिए कड़े नियम लागू किए जाने चाहिए। नदी के संरक्षण के लिए जल शुद्धिकरण संयंत्रों के अलावा, नदी के किनारे हरित पट्टियाँ विकसित करने और जलाशयों को पुनर्जीवित करने की योजना पर काम और तेजी से किया जाना चाहिए; यह न केवल नदी की जल गुणवत्ता को सुधारने में मदद करेगा, बल्कि स्थानीय पारिस्थितिकी तंत्र को भी पुनः स्थापित करेगा। स्थानीय समुदायों को भी प्रदूषण नियंत्रण और जल संरक्षण के उपायों के प्रति अधिक जागरूक करने के लिए प्रशिक्षण और शिक्षा कार्यक्रमों की आवश्यकता है। इसके लिए स्थानीय सरकारों को सामाजिक संगठनों के साथ मिलकर काम करना चाहिए तथा नदी के संरक्षण के लिए सरकारी योजनाओं के साथ-साथ स्थानीय स्तर पर नेतृत्व को प्रोत्साहित करने के लिए एक मजबूत सामुदायिक नेटवर्क स्थापित किया जाना चाहिए। वाराणसी में 'नमामि गंगे' जैसी परियोजनाओं के तहत, गंगा और उसकी सहायक नदियों को साफ करने के प्रयास किए जा रहे हैं, लेकिन इन परियोजनाओं की सफलता तब ही संभव है जब स्थानीय लोग और प्रशासन मिलकर काम करें, इस तरह के नेटवर्क के माध्यम से स्थानीय समुदायों को नदी के संरक्षण की दिशा में सक्रिय भागीदारी करने के लिए प्रेरित किया जा सकता है।

निष्कर्ष:

वरुणा नदी के संरक्षण और पुनरुद्धार के लिए सरकार और स्थानीय समुदायों दोनों द्वारा किए गए प्रयासों में उल्लेखनीय योगदान देखा गया है, सरकारी योजनाओं जैसे नदी पुनरुद्धार परियोजनाओं, जल शुद्धिकरण संयंत्रों की स्थापना, और प्रदूषण नियंत्रण उपायों के बावजूद, इन प्रयासों की सफलता के लिए अधिक समन्वय और दीर्घकालिक रणनीतियों की आवश्यकता है। स्थानीय समुदायों का सक्रिय योगदान भी नदी के संरक्षण में महत्वपूर्ण है, लेकिन इसे प्रभावी बनाने के लिए अधिक शिक्षा और जागरूकता की आवश्यकता है। जब सरकार और स्थानीय समुदाय मिलकर काम करेंगे, तो वरुणा नदी के पुनरुद्धार और संरक्षण के प्रयास अधिक प्रभावी साबित हो सकते हैं।

References:

1. Agrawala, A., Srivastava, P. K., Tripathi, V. K., Maurya, S., Sharma, R., & J., S. D. (2023). Future projections of crop water and irrigation water requirements using a bias-corrected regional climate model coupled with CROPWAT. *Journal of Water and Climate Change, 14* (4), 1147. https://doi.org/10.2166/wcc.2023.349
2. Chaubey, P., Kundu, A., & Mall, R. K. (2019). A geospatial inter-relationship with drainage morphometry, landscapes, and NDVI in the context of climate change: A case study over the Varuna River basin (India). Environmental Earth Sciences, 78(6), 1-16.
3. Chaurasia, J., Rai, P. K., & Singh, A. K. (2013). Physico-chemical status of groundwater near Varuna River in Varanasi city, India. *International Journal of Environmental Sciences,* Volume 3. https://doi.org/10.6088/ijes.2013030600027
4. Google Earth. (n.d.). Geographical coordinates of Varanasi, Uttar Pradesh. Retrieved from https://earth.google.com
5. Government of India. (2015). Clean Ganga Mission Report. New Delhi: Ministry of Water Resources.
6. Kumar. (2013). Pollution of the Ganga River Due to Urbanization of Varanasi: Adverse Conditions Faced by the Slum Population. *Environment and Urbanization ASIA*. https://doi.org/10.1177/0975425312473229
7. Mishra, A. (2011). Impact of Urbanization on the Hydrology of Ganga Basin (India). *Water Resources Management, 25*(2), 705-719. https://www.researchgate.net/publication/225445465_Impact_of_Urbanization_on_the_Hydrology_of_Ganga_Basin_India

8. Pandey M., Dixit V.K., Katiyar G.P., Nath G., Sundram S.M., Chandra N., Shomvansi A.K., Kar S., Upadhay V.K. (2005). Ganga water pollution and the occurrence of enteric diseases in Varanasi city. *Indian Journal of Community Medicine, 30*(4), 115–120.
9. Prakash, K., Singh, S., & Shukla, U.K. (2016). Morphometric changes of the Varuna River basin, Varanasi district, Uttar Pradesh. *Journal of Geomatics, Vol. 10*.
10. Raju, N. J., Ram, P., & Dey, S. (2009). Groundwater Quality in the Lower Varuna River Basin, Varanasi District, Uttar Pradesh. *Journal Geological Society of India, 23*, 178-192.
11. Sharma, S., Roy, A., & Agrawal, M. (2016). Spatial variations in water quality of the river Ganga with respect to land uses in Varanasi. Springer, Volume 23, 21872–21882.
12. The Varuna River: Geography and Hydrology, Varanasi Municipal Corporation.
13. Water Pollution in Varanasi: Challenges and Solutions, Varanasi Pollution Control Board.

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Mahakumbh 2025: Bridging Ancient Spirituality and Modern Economic Vitality

Chandra Sekhar Pratap Singh *
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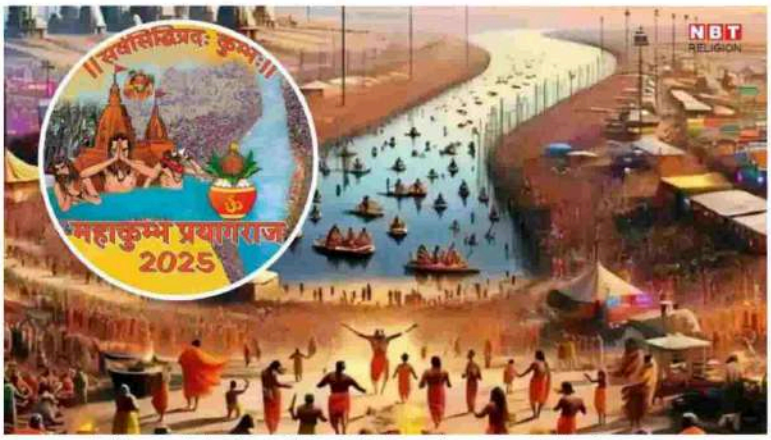

The Mahakumbh Mela, the world's largest spiritual congregation, is set to transform

Prayagraj into a global epicenter of devotion and cultural magnificence from January 13 to February 26, 2025. This 45-day celestial gathering at the sacred confluence of the Ganga, Yamuna, and Saraswati is a timeless celebration of India's spiritual heritage. With an expected 40 crore visitors, Mahakumbh 2025 is not just a religious event but a powerful driver of tourism, economic growth, and cultural diplomacy.

During the Maha Kumbh, demand for Kumbh Mela accommodation surges as millions visit these pilgrimage sites. This increase benefits hotels, restaurants, transport services, and tour providers. Services such as Kumbh Mela tent booking

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also see high demand, The tourism industry experiences a significant rise in air travel, rail, and road transport bookings, creating a windfall in revenue across these sectors. Additionally, the Maha Kumbh creates numerous temporary and permanent jobs, including roles in security, construction, health services, and event management.

In a significant administrative development, the Uttar Pradesh government has declared the Mahakumbh Mela area as a temporary district, known as the 'Mahakumbh Mela District,' for the duration of the event—from December 1, 2024, to March 31, 2025. This move aims to streamline management and ensure the smooth conduct of the Mela.

Prime Minister Narendra Modi has aptly highlighted the significance of this occasion, stating:

"The Maha Kumbh is going to be held in Prayagraj for 45 days from 13th January to 26th February. There are so many reasons to come to India together, asking the Indian diaspora to come to India during this time. First the NRI Day, then the Maha Kumbh, and after that the Republic Day, this is a kind of Triveni, a great opportunity to connect with the development and heritage of India."

This alignment of events—NRI Day, Mahakumbh, and Republic Day—symbolizes a Triveni Sangam of spirituality, nationalism, and cultural pride, fostering a stronger connection between India and its global diaspora.

Under the visionary leadership of Chief Minister Yogi Adityanath, Uttar Pradesh has made unprecedented strides in infrastructure and safety preparations for this grand event. The construction of new roads, bridges, and modern amenities has transformed Prayagraj into a world-class pilgrimage hub, ensuring comfort and accessibility for millions of visitors.

Important Bathing Dates:

January 13, 2025: Paush Purnima
January 14, 2025: Makar Sankranti (First Shahi Snan)
January 29, 2025: Mauni Amavasya (Second Shahi Snan)
February 3, 2025: Basant Panchami (Third Shahi Snan)
February 12, 2025: Maghi Purnima

February 26, 2025: Mahashivratri (Final Snan)

Historical Background and Significance of Maha Kumbh:

The Maha Kumbh Mela, often referred to as the largest spiritual gathering on Earth, finds its roots in ancient Indian mythology and scriptures. The origins of this grand event are traced to the 'Samudra Manthan' (churning of the cosmic ocean), a celestial event described in Hindu texts. During this divine churning, a pot (Kumbh) containing the nectar of immortality (Amrit) emerged, sparking a fierce battle between gods and demons for its possession. Legends state that a few drops of this nectar fell at four locations on Earth—Prayagraj, Haridwar, Ujjain, and Nashik—which became the sacred sites for the Kumbh Mela.

The Maha Kumbh Mela in Prayagraj, held once every 12 years, is celebrated at the confluence of the Ganga, Yamuna, and the mythical Saraswati rivers. It symbolizes spiritual cleansing, with devotees believing that a holy dip at the Triveni Sangam purifies the soul, absolves sins, and brings them closer to liberation (Moksha).

Over centuries, this mythological event has evolved into a grand socio-cultural phenomenon, drawing not only saints and pilgrims but also kings, scholars, and commoners alike. Historical accounts, such as those of the 7th-century Chinese traveler Huan Tsang, highlight the Mela's significance even in ancient times.

Today, the Maha Kumbh Mela is a living legacy of India's spiritual ethos, where celestial alignments dictate the festival's dates, reflecting the intrinsic connection between cosmic movements and human life. It is a confluence of India's spiritual, cultural, and social diversity, making it much more than a religious event—it is a celebration of collective faith and heritage.

Key Infrastructure Developments for Mahakumbh 2025

As Mahakumbh 2025 approaches, the transformation of Prayagraj into a vibrant global event hub has begun, marked by an extensive upgrade in infrastructure. The highlight of the preparation is the development of Mahakumbh Nagar 76th

district, a temporary city designed to accommodate millions of pilgrims and visitors.

Category	Details/Statistics
Duration	45 days (January 13 - February 26, 2025)
Expected Visitors	Over 40 crore (400 million)
Road Infrastructure	Renovation of **92 roads**; beautification of **17 roads**
Pontoon Bridges	Construction of 30 bridges using 3,308 pontoons; 28 are ready
Signage Installation	**800** multilingual signages planned; over **400** already installed
Checkered Plates Laid	**2,69,000** plates laid in the Mela area

- **Temporary City Setup:** The creation of Mahakumbh Nagar includes thousands of shelters, from basic tents to luxury accommodations. The IRCTC's "Mahakumbh Gram," a luxury tent city, offers high-end facilities to visitors, setting the stage for a comfortable spiritual experience.
- **Transportation and Connectivity**: Over 92 roads have been renovated, and 30 pontoon bridges are being constructed, ensuring seamless mobility. The inclusion of 800 multilingual signages will further assist the smooth navigation of visitors.
- **Security Measures**: State-of-the-art security systems, including AI-powered crowd density monitoring, thousands of CCTV cameras, facial recognition technology, and drones for aerial surveillance, ensure both the safety and efficiency of the event. Additionally, fire safety measures, including advanced Articulating Water Towers (AWTs) and underwater drones, are being deployed.

Security Measure	Details/Statistics
CCTV Cameras	2700 cameras with AI capabilities deployed for real-time monitoring
Facial Recognition Tech	Used at entry points for enhanced safety
Drones for Surveillance	Deployed for aerial monitoring
Underwater Drones	Capable of diving up to 100 meters for round-the-clock surveillance
Fire Safety Budget	₹131.48 crore allocated for fire safety measures
Police Deployment	Over 50,000 personnel, including paramilitary forces

- **Public Utilities and Hygiene**: More than 2.69 lakh checkered plates are being laid to ensure safe walkways, and robust waste management systems, including mobile toilets, are in place to maintain cleanliness. A strong focus is being placed on the health and safety of the attendees, as well as environmental sustainability.
- **Healthcare Initiatives**: The "Bhishma Cube" temporary hospital, capable of treating up to 200 people, along with specialized camps for eye care and vulnerable groups, will ensure medical facilities are readily available. The "Netra Kumbh" initiative aims to provide eye care to over 5 lakh pilgrims.
- **River Protection**: In a bid to preserve the sanctity of the Ganga and Yamuna, three sewage treatment plants are being set up, ensuring clean water during the event. Additionally, the use of solar power, eco-friendly materials, and a ban on single-use plastics are helping make the event sustainable.

Economic Impact of Mahakumbh 2025

The Mahakumbh is not just a spiritual gathering, but a significant economic driver for Uttar Pradesh, attracting millions of pilgrims and tourists from around the world. The Maha Kumbh Impact on Economy is undeniable, as each Kumbh Mela festival boosts both the national and state economies significantly. In 2025, Prayagraj is expected to welcome between 40 to 45 crore visitors, generating substantial economic activity. Events like the Maha Kumbh not only hold religious significance but also spur economic development, job creation, and tourism, benefiting local businesses and promoting overall economic growth in India.

Mahakumbh 2025 is expected to create a transformative impact on Uttar Pradesh's economy, emerging as a powerful engine for growth. Historically, the Kumbh Mela has been a lucrative event, with the 1882 Kumbh generating substantial profits, and the upcoming Mahakumbh is projected to continue this legacy with an estimated revenue of Rs 25,000 crore for the state. The sheer scale of the event, with 40-45

crore pilgrims expected to gather over a span of weeks, sets it apart as the world's largest religious gathering. This year's Mahakumbh will cover 4,000 hectares and is expected to generate significant economic benefits across various sectors.

The UP government has already allocated Rs 5,600 crore for event management and infrastructure development, with a total budget of Rs 6,382 crore. Additionally, the event's broader economic impact is expected to reach Rs 3.2 lakh crore, according to economic advisor KV Raju. Former IAS officer Awanish Awasthi highlights that even a modest Rs 8,000 spend per pilgrim could push the figure into the multi-lakh crore range, underlining the immense financial activity at play. While much of this will be in the form of unorganised transactions—such as payments for food, transport, and local services—the economic gains for small vendors and local businesses are undeniable.

Local businesses, such as street vendors, boat operators, and hotel owners, are already reporting a surge in income. Rajesh Tiwari, a street food vendor, notes that earnings during the event will surpass six months of regular business. Furthermore, the Uttar Pradesh government has already trained 45,000 families in hospitality and tourism services, creating a workforce that will cater to the millions of visitors. Temporary infrastructure projects like a Rs 275-crore railway overbridge and the six-lane Ganga bridge will not only ease pilgrim movement during Mahakumbh but also leave behind long-term enhancements that will continue benefiting the region's connectivity and tourism well after the event concludes.

The event's success will also be bolstered by private sector involvement. Corporations are investing significantly in branding and sponsorship, which further strengthens the economic ecosystem around Mahakumbh. The contribution of these investments will help elevate Uttar Pradesh's profile on the global tourism map, ensuring the region continues to attract international visitors long after the Mahakumbh is over.

With an expected rise in international tourism, infrastructure improvements, and job creation, the Mahakumbh 2025 promises to significantly contribute to the long-term economic vitality of Uttar Pradesh, transforming the region into a global spiritual and economic hub.

- **Tourism and Cultural Promotion:** The Uttar Pradesh Pavilion showcases key tourism circuits like the Ramayana and Krishna-Braj Circuits, alongside cultural programs. The state's rich cultural heritage is reflected through performances, exhibitions, and temple renovations like the Nagvasuki and Hanuman Temple corridors.
- **Economic Growth:** The Mahakumbh generates substantial revenue, with projections estimating Rs 25,000 crore in revenue for the state. The event also drives local trade, with increased sales of Mahakumbh-themed products, boosting small businesses and local industries. Over 50,000 people, including workers in hospitality and tourism, have found employment opportunities linked to the event.
- **Job Creation and Local Empowerment**: The Uttar Pradesh government has trained 45,000 families in hospitality and service sectors, promoting skill development and enhancing selfemployment opportunities. Local products from various districts, such as Banaras sarees and Moradabad brassware, are expected to gain international recognition, in line with Prime Minister Modi's "Vocal for Local" initiative.

Global Impact and Special Projects for Mahakumbh 2025

The scale of Mahakumbh 2025 extends far beyond India's borders, with millions of international visitors and a significant global economic impact.

International Visitor Arrivals: With pilgrims expected from over 75 countries, the Mahakumbh is poised to enhance India's profile as a global spiritual and cultural destination. Special arrangements are in place for foreign tourists, including multilingual signages and cultural programs.

Transport and Connectivity: Special trains connecting Prayagraj to key religious sites like Varanasi, Ayodhya, and Mathura will facilitate pilgrimages, creating a seamless travel

experience for the visitors.

Private Sector Involvement: Corporations are investing heavily in branding and marketing opportunities during Mahakumbh. With an estimated Rs 3,000 crore expected from India Inc., the event also draws significant corporate sponsorships and investments.

Conclusion

Mahakumbh 2025 is poised to be a historic confluence of spirituality and modernity, attracting millions while driving significant economic growth. The multifaceted infrastructure improvements, health and security provisions, cultural promotions, and sustainable initiatives reflect Uttar Pradesh's commitment to enhancing both the visitor experience and long-term development. Beyond the religious significance, Mahakumbh 2025 stands as a testament to the power of cultural events in driving economic prosperity, reinforcing the "Vocal for Local" ethos, and boosting India's position on the global stage.

Reference :

- **Buzinde, C. N., Kalavar, J. M., Kohli, N., & Manuel-Navarrete, D. (2014).Emic understandings of Kumbh Mela pilgrimage experiences.** ***Annals of Tourism Research***
- **Anurag Roushan (2024) Mahakumbh Mela 2025: How will the grand event boost economy of Uttar Pradesh? EXPLAINED**
- **Divyata Yadav, Akshita Choudhary & P. K. Joshi (2024) . Cultural heritage and urban morphology: land use transformation in 'Kumbh Mela' of Prayagraj, India**
- **https://www.ndtv.com/feature/maha-kumbh-2025-know-historylocation-significance-and-more-7302358**
- **https://mahakumbh.in/influence-of-kumbh-mela-on-indian-culture**
- **https://pib.gov.in/PressReleaseIframePage.aspx**

- **https://www.aninews.in/news/business/mahakumbh-boosting-localeconomy-besides-being-a-spiritual-event20241229175145**
- **https://www.opindia.com/2024/12/prayagraj-maha-kumbh-acelebration-of-faith-and-a-major-boost-to-economy**
- **https://mahakumbh.in/influence-of-kumbh-mela-on-indian-culture**
- **https://www.firstpost.com/explainers/maha-kumbh-mela-2025boost-uttar-pradesh-economy-13848023.html/amp**
- **https://www.moneycontrol.com/news/india/mahakumbh-2025-aspectacle-blending-faith-with-economic-prosperity-12889849.html**
- **https://www.thekumbhmelaindia.com/maha-kumbh-impact-oneconomy-understanding-the-economic-benefits-of-the-maha-kumbhmela**
- **https://timesofindia.indiatimes.com/city/allahabad/kinnar-akharalaunches-global-expansion-initiative-for-transgenders-at-maha-kumbh-2025/articleshow/115027249.cms**

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Plant Growth Promoters and Genotype: Strategies to Enhance Growth, Productivity and Profitability of Wheat in Semi-Arid Ecologies of India

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Abstract

Declining soil health and nutrient imbalance in continuous rice-wheat systems threaten wheat productivity and profitability. A two-year (2021-22 and 2022-23) field experiment was conducted in a split-plot design to evaluate the combined effects of wheat genotypes and plant growth promoters (PGPs) on growth, physiology, and yield under semi-arid conditions. Treatments comprised three wheat genotypes (DBW-187, K-1006, and K-607) and five plant growth promoter (PGP) options: control (no PGP), chelated micronutrients (0.5%), seaweed extract applied as granules (25 kg ha^{-1}) and liquid (3000 ppm), gibberellic acid (2000 ppm), and nitrobenzene (3000 ppm). DBW-187 exhibited superior growth and yield attributes, with higher tiller number (~20%), dry matter accumulation (~18%), chlorophyll content, and grain yield (~13%) over other genotypes. Chelated micronutrients enhanced growth parameters and yield (grain+20.2%, straw+9.4%) compared with the control. Seaweed extract and gibberellic acid produced comparable improvements. The combination of DBW-187 with chelated micronutrients achieved the highest production and economic efficiency. Integrating high-yielding genotypes with suitable PGPs and balanced fertilization offers a promising strategy for improving wheat productivity and sustainability in agri-food systems.

Keywords Gibberellin · Growth; micronutrients · Nitrobenzene · Seaweed extract · Yield

Introduction

As a global staple crop, wheat (*Triticum aestivum* L.) feeds billions of people, contributing ~20% of human caloric intake and delivering a rich supply of carbohydrates (74.88%), protein (10.55%), and vital nutrients critical for health and agri-food and nutritional security (Kulkarni et al. 2012; Ulukan 2024). It accounts for ~30% of cereal production, yielding 791.21 million tons (Mt) from 222.93 million hectares (Mha) globally (USDA 2024). By 2050, wheat demand is expected to rise by ~60% to feed an estimated 9.7 billion people (Lal 2016; Erenstein et al. 2022). In India,

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wheat is the second most important cereal crop after rice, primarily grown in the northern and central regions, contributing to agri-food security and the agricultural economy (Prasad 2005; Singh and Sidhu 2014). Despite being one of the largest wheat producers, India's average wheat yield (3.5 t ha^{-1}) lags behind that of countries like China and Mexico, where yields approach ~ 5 t ha^{-1}.

The current productivity of wheat is insufficient to meet the future global demand. Wheat production is constrained by several biotic stresses such as insect pests and diseases including termites and blast (Asseng et al. 2013; Akbar et al. 2023; Bakala et al. 2021) and by numerous abiotic stresses, including rising global temperatures, erratic rainfall, hailstorms, drought, and salinity, which alone can reduce yields by 20–30% (Liu et al. 2016; Zhang et al. 2022). In addition, shrinking cultivable land, increasing pressure on water resources, and imbalanced plant nutrition further limit productivity. To address these challenges, integrated nutrient management approaches using organic manures (FYM, vermicompost), green manuring (legumes), biofertilizers (Rhizobium), essential nutrients (N, P, K, S, and micronutrients such as Fe, Zn, Mn, and Cu), and plant growth promoters (e.g., seaweed extract, gibberellic acid, nitrobenzene) have been recommended to sustain and enhance wheat productivity (Jat et al. 2014; Udgata et al. 2020; Sande et al. 2024; Meena et al. 2017).

To achieve the maximum level of productivity, maintaining soil health is essential through the optimal management of plant growth factors such as soil, water, and nutrients (Das et al. 2015). Among the key factors distinguishing crop productivity, PGPs such as seaweed extract (liquid and granules), gibberellin (GA_3), nitrobenzene (NB) and mixture of micronutrients (Fe, Zn, Cu and Mn) significantly impact the growth and yield potential of wheat genotypes (Benítez García et al. 2020; Nagar et al. 2022; Ali et al. 2021). PGPs play an essential role in plant metabolism such as photosynthesis, respiration, carbohydrate and nitrogen metabolism, protein synthesis, lipid metabolism, hormone biosynthesis, water and ion transport and, uptake and stress metabolism (Muhammad et al. 2021; Chauhan et al. 2023). It also enhances plant biomass, root development, nutrient uptake, stress tolerance, increases chlorophyll content, improves flowering and enhances grain yield and productivity of wheat (Nadeem and Farooq 2019).

Seaweeds are renewable marine macro-algae that serve as rich sources of both major (P, K, and Ca) and minor nutrients (Fe, Zn, Cu, Mn, B, Mo, and Co). They also contain amino acids, vitamins, and PGP substances such as auxins, gibberellins, cytokinins, abscisic acid, betaines, and sterols (Rathore et al. 2009). Seaweed extract enhance crop growth and yield (Yao et al. 2020), improve plant resilience to environmental and biotic stresses (Parađiković et al. 2019), increase nutrient and water uptake from the soil (Yao et al. 2020), and boost antioxidant activity and metabolic efficiency in plants (Rathore et al. 2009), they also improves soil health (Khan et al. 2009; Kumar and Sahoo 2011; Choudhary et al. 2019).

Gibberellic acid (GA or GA_3) is a naturally occurring plant hormone that promotes growth and development in plants (Lamlom et al. 2025). Gibberellic acids are involved in various hormonal and metabolic activities in plants, including breaking seed dormancy, enhancing germination, promoting hypocotyl elongation, and increasing leaf size (Hussien Ibrahim et al. 2019). They also contribute to floral initiation, synchronized flowering, development of floral organs, reduced time to flowering, and an increase in the number of flowers (Bahrani and Pourreza 2012) and influence the size and trigger the production of certain hydrolytic enzymes in the aleurone layer of cereal grains (Swain and Singh 2005). GA_3 is applied exogenously to crops to improve growth, morphological, physiological, biochemical processes, yield components and yield (Chauhan et al. 2018; Prajapati et al. 2023) and help wheat genotypes cope with biotic and abiotic stressors like drought and salinity (Bahrani and Pourreza 2012). The increasing antioxidant enzyme activity, in the removal of excess reactive oxygen species (ROS), is protects the plant (Lamlom et al. 2025). Nitrobenzene is an aromatic organic compound mixture of growth regulators and nitrogen that acts as a growth enhancer, stimulates flowering, prevents shading is a yield booster (Kohombange et al. 2018). When used in small amounts, nitrobenzene can act as a growth promoter that improves plant biomass, photosynthesis, flower initiation, marketable yield, and wheat grain quality (Deb et al. 2012).

Micronutrients like Fe, Zn, Cu, and Mn are crucial for wheat crop growth and development, playing a vital role in physiological and biochemical processes (Nadeem and Farooq 2019). Micronutrients (Fe, Zn, Cu, Mn) enhance crop growth, photosynthesis, chlorophyll content, leaf area, dry matter accumulation, yield attributes, and overall health and increased yield (Dhaliwal et al. 2022). Micro- and macro-nutrients are equally crucial in plant metabolic processes (Nadeem and Farooq 2019). They have diverse roles of oxygen carriers in nitrogen fixation, metabolism, nutrient uptake, protein synthesis, carbonic anhydrase activity, enzyme activation, electron transport, and disease resistance (Zeidan et al. 2010). Plant growth and crop productivity is hampered by a lack of micronutrients, especially when soil health declines (Sharma et al. 2023).

Amidst global efforts toward sustainable agri-food production, integrating nutrient management (INM) with improved wheat genotypes in the Indo-Gangetic Plains (IGPs) is vital to enhance yield and grain quality, advancing agri-food security and sustainability goals. This study

explored the impact of INM on wheat genotypes in the IGPs, emphasizing its sustained effects on grain yield and quality. The research aimed to offer targeted recommendations for wheat cultivation in this region, considering existing research gaps and regional specificities.

To address these gaps, the impact of organic and inorganic PGPs (plant growth promoters) on the growth and yield potential of wheat genotypes in the IGPs was investigated. The following research objectives were established: (i) to evaluate the performance of wheat genotypes; (ii) to assess the effect of PGPs on growth, yield attributes, and productivity of wheat genotypes; and (iii) to examine the impact of PGPs on the physiological, morphological, and biochemical traits of wheat genotypes.

Materials and Methods

Experimental Site and Climatic Conditions

The field experiments were conducted over two consecutive cropping seasons (2021-22 and 2022–23) at C.S. Azad University of Agriculture and Technology (26.49°N; 80.29°E; 125.9 m aMSL), Kanpur, India (Fig. 1). Located in the IGPs, the experimental site experiences a humid sub-tropical climate with cold winters and hot summers, with mean minimum and maximum temperatures of 4.9 °C and 41.8 °C, respectively. The mean annual rainfall was 898 mm, with the majority (~89%) of the precipitation occurring during the monsoon season (July to September). The peak rainfall typically occurred in the second week of September in both years (Fig. 2a-b). The experimental site had a five-year history of rice-wheat rotation with varied tillage and nutrient practices. The sandy clay loam soil was classified as typical alluvial Inceptisol. The surface layer (0–0.15 m) of the soil has a pH of 7.7 (measured using a 1:2.5 soil-to-water ratio, Piper 1950), organic carbon content of 0.49% (Walkley and Black 1934), $KMnO_4$-oxidizable nitrogen of 149.87 kg ha^{-1} (Subbiah and Asija 1956), $NaHCO_3$-extractable phosphorus of 20.60 kg ha^{-1} (Olsen et al. 1954), NH_4OAc-exchangeable potassium of 310.45 kg ha^{-1} (Hanway and Heidel 1952), available sulfur of 12.56 kg ha^{-1} (Williams and Steinbergs 1959), 2.78 ppm iron (Fe), and 2.38 ppm zinc (Zn), as per the methods outlined by Lindsay and Norvell (1978).

Experimental Design and Genotypes Details

The experimental trials were conducted using a split-split plot design (SPD) with three main plot treatments and six subplot treatments, replicated three times. The study was carried out over both years in the same plots, with gross plot dimensions of 5.0 m × 4.0 m and a net plot size of 4.0 m × 3.4 m. The treatments included three wheat genotypes in the main plots and six plant growth promoters in the subplot treatments (Fig. 3). Three high-performing wheat genotypes were selected for the study: (i) DBW-187 (Karan Vandana), recommended for irrigated, timely-sown conditions with high disease resistance; (ii) K-1006 (Shekhar), popular for timely sowing, and (iii) K-607 (Azad), also, best sown mid-November and recommended for IGPs.

Field Preparation and Sowing Protocols

The field was well prepared with adequate soil moisture following pre-sowing irrigation (*Paleo*) about 10 days before sowing. Initial tillage included disc ploughing, two cross ploughings with a cultivator, and rotavator. Certified seeds of DBW-187, K-1006, and K-607 were manually sown on 29 November 2021 and 8 November 2022 under optimal moisture to ensure good germination. A uniform seed rate of 100 kg ha^{-1} was maintained with spacing of 22.2 × 10 cm. After sowing, adequate planking was done to cover the seeds in the furrows adequately.

Fertilizer Management

Fertilizers were applied using neem-coated urea (NCU) for nitrogen (N), single superphosphate (SSP) for phosphorus (P), and muriate of potash (MOP) for potassium (K). Each plot received a uniform fertilizer application of 120 kg N, 60 kg P_2O_5, and 40 kg K_2O per hectare in both years. The full doses of phosphorus and potassium, along with half of the N dose, were applied as a basal dose and incorporated into the soil during the final land preparation just before sowing. The used seaweed extract was a commercially available *Ascophyllum nodosum* based formulation (e.g., Seaweed Gel/Liquid or equivalent product), derived from brown marine algae known for its natural plant growth promoting compounds such as cytokinins, auxins, betaines, and micronutrients. The remaining N dose was applied in two split doses as top dressing: (i) at the crown root initiation (CRI) stage and (ii) at the flowering stage. Plant growth promoters were applied at specific crop growth stages: (i) Nitrobenzene at 3000 ppm during the tillering (30–35 DAS) and flowering stages (65–70 DAS), (ii) Gibberellic acid at 2000 ppm during the tillering (30–35 DAS) and flowering stages (65–70 DAS), (iii) seaweed extract was applied in two forms: [(a) granular form at a rate of 25.0 kg ha^{-1}, incorporated into the soil as a basal application at sowing, and (b) liquid form at a concentration of 3000 ppm, applied as a foliar spray at the tillering (30–35 DAS) and flowering stages (65–70 DAS)], with three replications. For each experimental plot (measuring 5.0 m × 4.0 m; 20 m^2), the corresponding quantity of seaweed granules was 50 g plot^{-1}, while the foliar

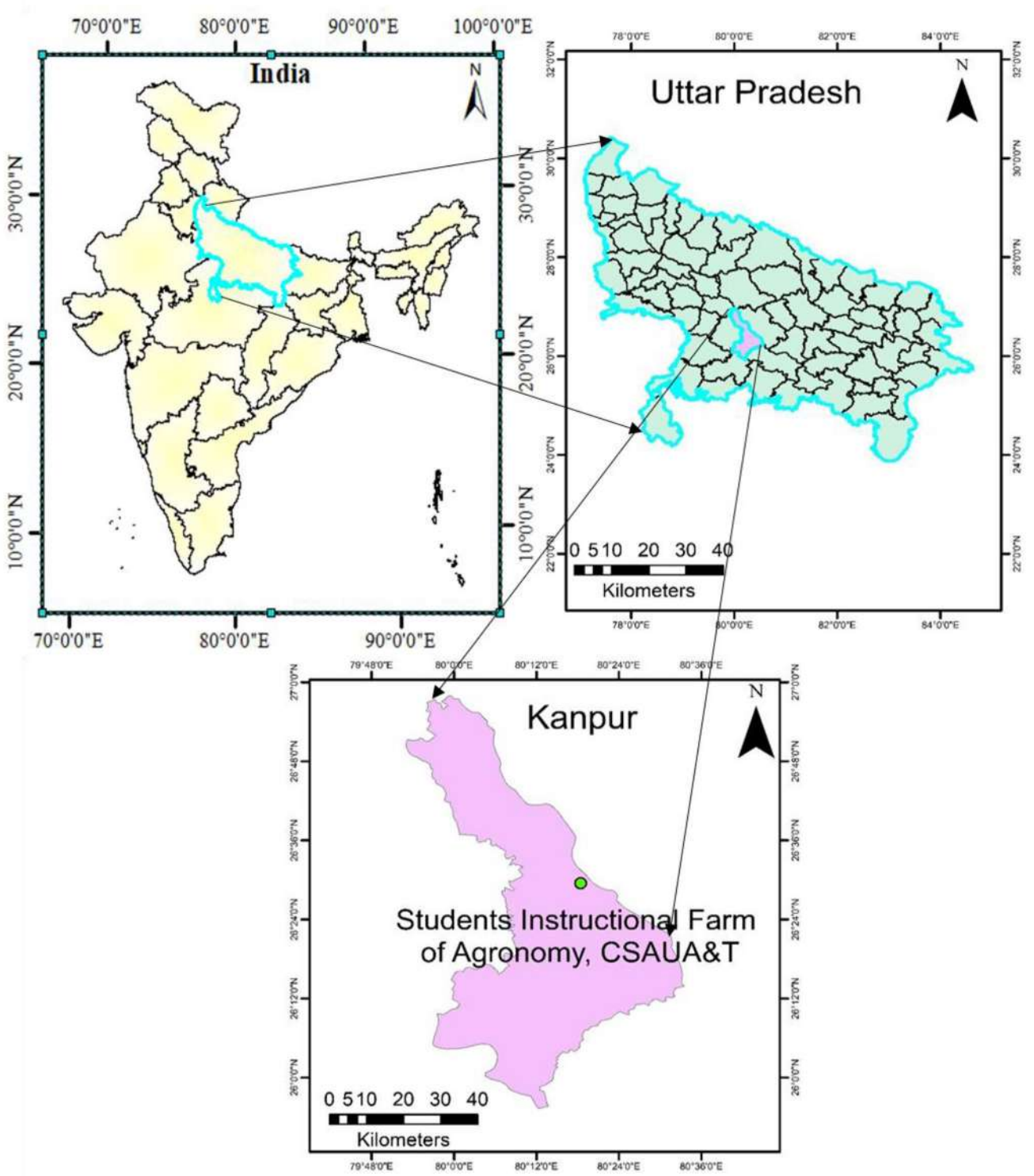


Fig. 1 Location of the study area

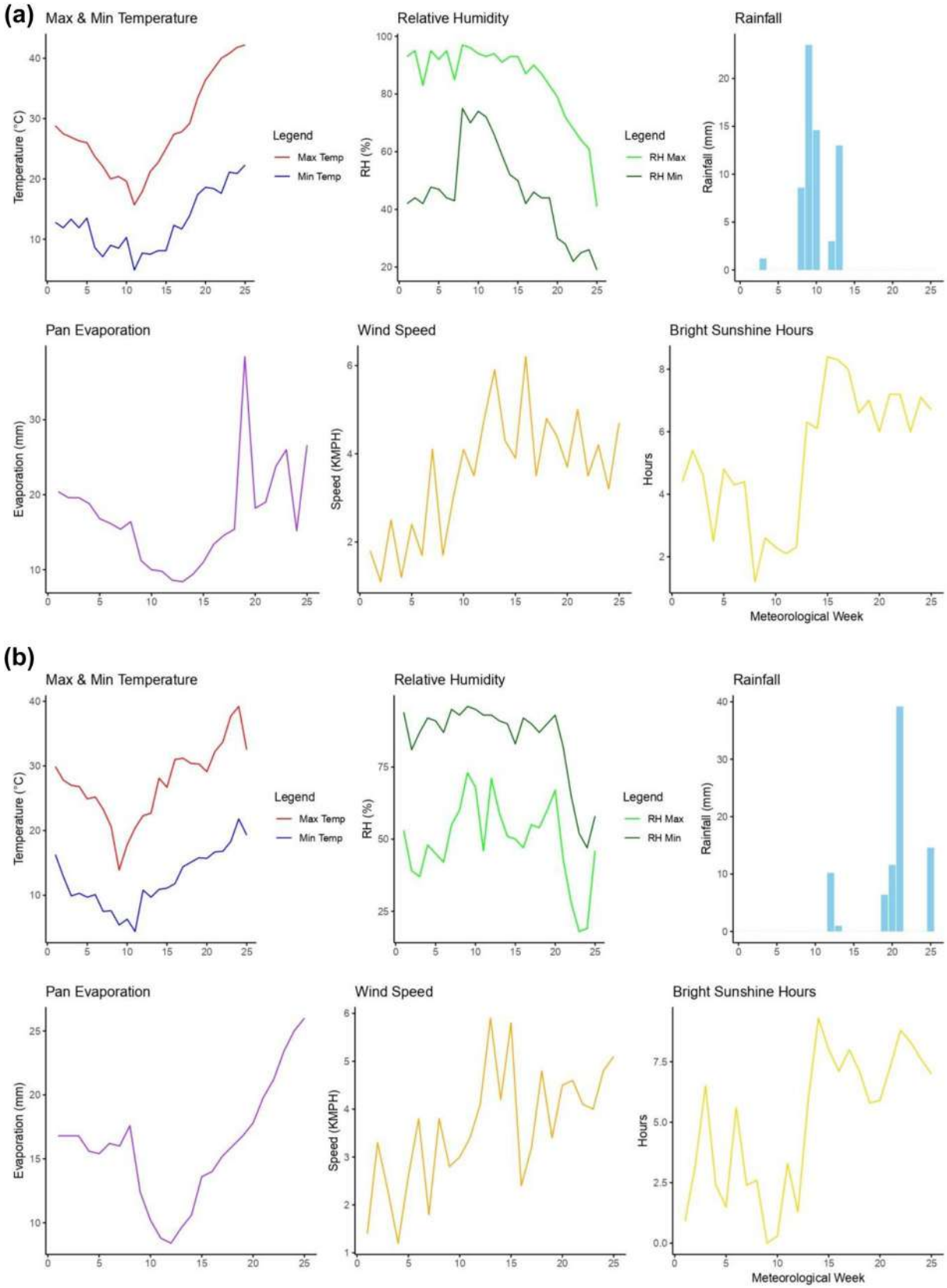


Fig. 2 (**a**) Average of weekly meteorological parameters during the wheat growing seasons during 2021-22. (**b**) Average of weekly meteorological parameters during the wheat growing seasons during 2022-23

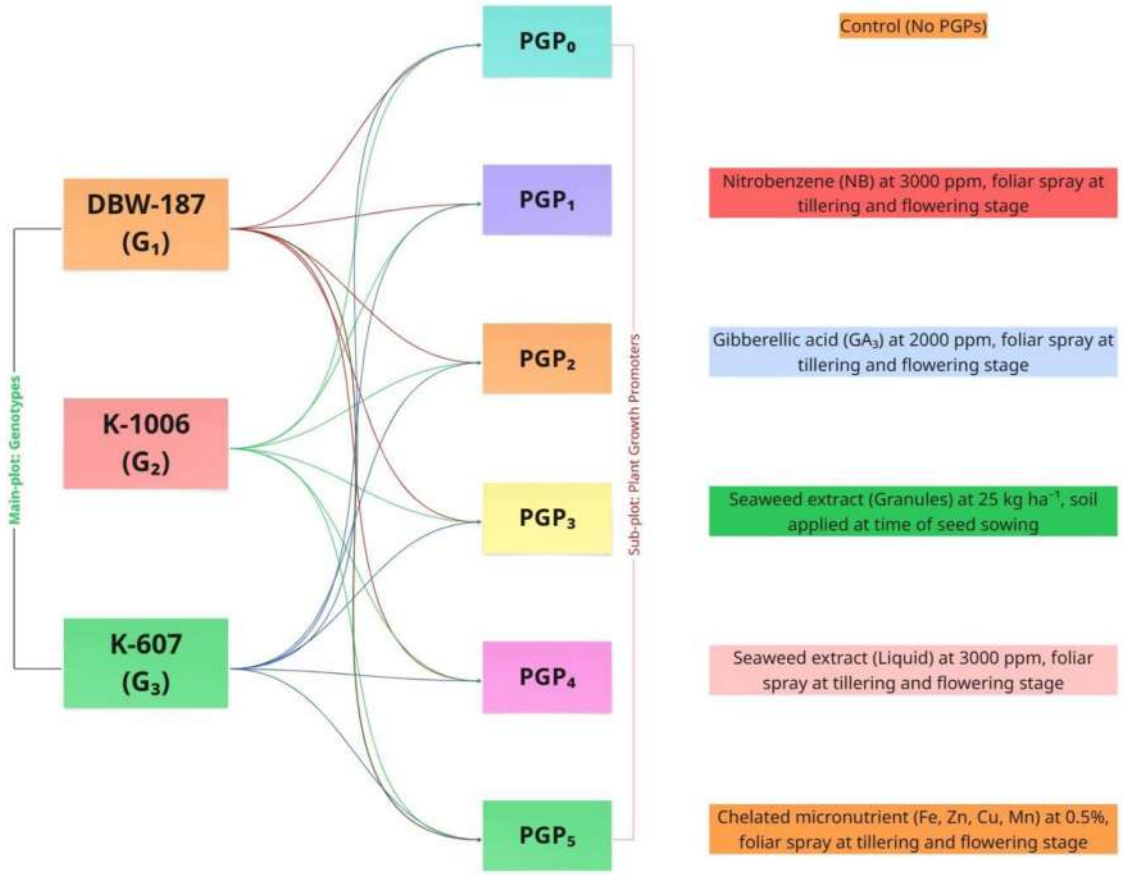


Fig. 3 Details of treatments used in the two-year wheat field experiment

application volume of liquid extract was 500 mL plot^{-1}, prepared and applied uniformly using a hand-operated knapsack sprayer, and (v) micronutrients (Zn, Fe, Cu, B) at 0.5% concentration during the same stages.

Weed and Water Management

Pendimethalin (Stamp) was applied as a pre-emergence herbicide at 1 kg a.i. ha^{-1}. Post-emergence herbicides Clodinafop-propargyl (*Topik*) at 80 g a.i. ha^{-1} and Metsulfuron-methyl at 6 g a.i. ha^{-1} were uniformly applied at 30–35 days after sowing in all plots. The experiment was carried out under irrigated conditions with a total of five irrigations, including pre-sowing irrigation. The first irrigation was applied at the crown root initiation (CRI) stage, which occurred between 21 and 25 days after sowing (DAS). The remaining three irrigations were provided at approximately 20-day intervals to meet the crop's water requirements.

Harvesting Protocols

Harvesting was performed when the ear heads turned golden yellow and the leaves and stems were fully dried. Plants were cut close to the ground and allowed to dry further in the field. Harvesting was done on the net plot area (4.0 m × 3.4 m) for each treatment. Threshing was conducted using a mechanical thresher on a net plot basis, and grain and straw yields were recorded, grain yields were reported at 13% moisture content.

Plant Growth and Biochemical Analysis

Measurements were taken at 30, 60, 90, and 120 days after sowing (DAS), as well as at harvest, during both years of the experimentation. Plant height and yield attributes were recorded from five randomly selected, tagged plants per plot. Tiller density was assessed by counting the number of tillers at three randomly selected spots within a one-meter row, averaging the values, and converting them to a per square meter basis. Dry matter accumulation (DMA) was estimated by harvesting a 50 cm row (four randomly selected spots) segment from the sampling rows in both years. The same sample was used to measure leaf area. The samples were sun-dried for 2–3 days, followed by oven-drying at 60 ± 2 °C for 24 h (Zhiipao et al. 2023). Tillers production rate (TPR) was a measure of how quickly new tillers emerge over a

given period in a given area, it was estimated by counting the number of tillers m^{-2} at periodical intervals.

$$\text{Tiller production rate } \left(\text{Tillers m}^{-2}\ \text{day}^{-1}\right) = \frac{\text{Tn}_2 - \text{Tn}_1}{(\text{T}_2 - \text{T}_1)} \quad (1)$$

[Whereas, Tn_1 and Tn_2 represent the number of tillers m^{-2} at time T_1 and T_2, respectively]

Plant growth was evaluated at various stages using DMA and LAI to determine the following growth parameters: (i) Crop Growth Rate (CGR): Represents the increase in dry weight per unit area over time (g m^{-2} day^{-1}), reflecting overall crop productivity (Watson 1958), (ii) Relative Growth Rate (RGR): Indicates the efficiency of plant growth per unit of existing biomass over time (g g^{-1} day^{-1}) (Redford 1967), (iii) Net Assimilation Rate (NAR): Measures dry matter production per unit leaf area, serving as an indicator of photosynthetic efficiency (mg m^{-2} day^{-1}) (Vernon and Allison 1963).

$$\text{Crop Growth Rate } \left(\text{g m}^{-2}\text{day}^{-1}\right) = \frac{\text{W}_2 - \text{W}_1}{(\text{T}_2 - \text{T}_1)\,\text{S}} \quad (2)$$

$$\text{Relative Growth Rate } \left(\text{g g}^{-1}\text{day}^{-1}\right) = \frac{\text{Log}_e\text{W}_2 - \text{Log}_e\text{W}_1}{(\text{T}_2 - \text{T}_1)} \quad (3)$$

$$\text{Net Assimilation Rate } \left(\text{mg m}^{-2}\text{leaf area day}^{-1}\right) = \frac{(\text{W}_2 - W_1) \times (\log_e\text{LAI}_2 - \log_e\text{LAI}_1)}{(\text{T}_2 - \text{T}_1) \times (\text{LAI}_2 - \text{LAI}_1)} \quad (4)$$

[Whereas, W_1 and W_2 are plant dry weight (g) at time T_1 and T_2, respectively and, S is land area (m^2) over which dry matter accumulation was recorded, LAI_1 and LAI_2 are leaf area index at time T_1 and T_2, respectively].

The area of fresh green leaves under each treatment was measured using a leaf-area meter (Model LICOR 3000, USA).

$$\text{Leaf Area Index (LAI)} = \frac{\text{Total leaf area } (cm^{-2})}{\text{Ground area } (cm^{-2})} \quad (5)$$

Physiological Indicators

Chlorophyll content in wheat leaves was measured using a SPAD-502 Plus chlorophyll analyzer (Konica Minolta Camera Co., Japan). Measurements were taken from the fully expanded middle portion of the leaf while avoiding the midrib region. Observations were recorded on five randomly selected plants per plot at 30 and 60 DAS from the uppermost fully expanded leaf, and at flowering from the flag leaf, between 10:00 AM and 4:00 PM under clear sky conditions to minimize diurnal variation. The Normalized Difference Vegetation Index (NDVI) was recorded using a handheld GreenSeeker® active optical sensor (Trimble Navigation Ltd., USA). Readings were taken at 30, 60 DAS, and flowering, between 10:00 AM and 2:00 PM, when solar radiation was stable and leaf turgidity was optimal. The sensor was held ~ 60 cm above the crop canopy, and values were averaged from five random points per plot along the central rows to avoid border effects (Yengoh et al. 2015; Chowdhury et al. 2018). Stomatal conductance (gs) was measured using an SC-1 Leaf Porometer (Decagon Devices, USA) on the adaxial surface of the flag leaf at 60 DAS and flowering stages. Measurements were taken between 10:00 AM and 12:00 PM under uniform light intensity and temperature conditions to ensure consistency. Four representative leaves per plot were measured, and the mean value was used for analysis.

Quantification of Leaf Chlorophyll and Carotenoids

Fresh leaf material was processed immediately after collection or samples were stored (−20 °C) using the non-maceration method of estimation. After finely chopping, 100 mg portions were weighed and placed into test tubes containing 10 ml DMSO. The test tubes were left overnight to allow extraction. The resulting extract was then analyzed by measuring absorbance at 480, 510, 645, and 663 nm using a UV-visible spectrophotometer (Analytik Jena AG Specordplus 210, Germany), with DMSO (99.95%) used as the blank. Chlorophyll a, b (calculated using the Arnon equation), total chlorophyll, the chlorophyll a: b ratio, and carotenoids were determined using the appropriate formulas (Eqs. 6-10).

$$\text{Chlorophyll a} = (12.7 \times \text{OD at } 663) - (2.69 \times \text{OD at } 645) \times \frac{\text{V}}{1000 \times \text{W}} \quad (6)$$

$$\text{Chlorophyll b} = (22.9 \times \text{OD at } 645) - (4.68 \times \text{OD at } 663) \times \frac{\text{V}}{1000 \times \text{W}} \quad (7)$$

$$\text{Total Chlorophyll} = (8.02 \times \text{OD at } 663) - (20.2 \times \text{OD at } 645) \times \frac{\text{V}}{1000 \times \text{W}} \quad (8)$$

$$\text{Chlorophyll a : b} = \frac{\text{Chlorophyll a}}{\text{Chlorophyll b}} \quad (9)$$

$$Carotenoids = (7.6 \times \text{OD at } 480) - (1.49 \times \text{OD at } 510) \times \frac{V}{100 \times W} \quad (10)$$

[Whereas, OD = Optical density, V = Volume of supernatant (ml), W = Weight of the leaf sample (g)]

Production and Economic Efficiency

Production efficiency measures the grain yield obtained per unit of time, calculated by dividing the total yield by the crop duration and expressed as kg ha^{-1} day^{-1}. It indicates how efficiently the crop was produced over its growing period (Eq. 11).

$$\text{Production efficiency } \left(\text{kg ha}^{-1}\text{day}^{-1}\right) = \frac{\text{Grain yield of the crop } \left(\text{kg ha}^{-1}\right)}{\text{Duartion of the crop (days)}} \quad (11)$$

Monetary efficiency was calculated by dividing the total net returns by the duration of the crop cycle, and was expressed as \$ ha^{-1} day^{-1}. It reflects the net returns generated by the crop, distributed over the growing period (Eq. 12).

$$\text{Monetary efficiency } \left(\$\ \text{ha}^{-1}\ \text{day}^{-1}\right) = \frac{\text{Net returns } \left(\$\ \text{ha}^{-1}\right)}{\text{Duration of the crop (days)}} \quad (12)$$

Statistical Analysis

The collected data of both cropping seasons on growth attributes, yield, yield components, and the physiological, morphological, and biochemical characteristics of wheat were subjected to statistical analysis using analysis of variance (ANOVA) in SAS 9.3 software (SAS Institute Inc., Cary, NC, USA). Significant differences among treatment means were determined using the F-test (Gomez and Gomez 1984). The LSD (Least Significant Difference) test was used to compare the treatment means at a 5% probability level. Pearson correlation coefficients were calculated to examine the relationships between growth attributes, yield, yield components, and the physiological, morphological, and biochemical characteristics of wheat. All analyses were performed using the Data Analysis Toolpak in Microsoft Excel 2007.

Results

Effect on Plant Height and Tillering

Genotypes and PGPs significantly influenced spring wheat height and tiller numbers, with pooled two-year data showing consistent differences across all growth stages (Table 1). Among genotypes, DBW-187 had the tallest plants and

Table 1 Effect of wheat genotypes and plant growth promoters on plant height and tiller number of spring wheat (mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3

Treatments	Plant height (cm)					Tillers m^{-2}				
	CRI	Tillering	Flowering	Ripening	Harvest	CRI	Tillering	Flowering	Ripening	Harvest
Genotypes										
G1	14.66 ± 0.10a	72.73 ± 0.51a	102.8 ± 0.64a	106.24 ± 0.65a	106.78 ± 0.62a	319.69 ± 3.03a	435.33 ± 7.94a	455.74 ± 9.79a	426.70 ± 10.70a	397.33 ± 12.40a
G2	14.45 ± 0.11b	71.82 ± 0.46b	99.7 ± 0.75b	102.61 ± 0.84b	103.14 ± 0.96b	301.38 ± 3.37b	410.17 ± 7.51b	427.87 ± 8.73b	398.12 ± 10.02b	366.19 ± 11.85b
G3	13.26 ± 0.07c	64.00 ± 0.48c	90.2 ± 0.59c	96.63 ± 0.82c	97.24 ± 0.79c	280.63 ± 3.35c	373.41 ± 7.91c	389.34 ± 9.49c	358.72 ± 10.75c	324.49 ± 12.78c
SEm±	0.010	0.052	0.095	0.136	0.202	0.562	0.309	0.501	0.595	1.058
LSD (≤0.05)	0.040	0.203	0.373	0.535	0.795	2.207	1.212	1.967	2.337	4.155
Plant growth promoters (PGPs)										
PGP0	14.03 ± 0.19b	67.45 ± 1.38d	94.76 ± 1.87d	98.21 ± 1.40d	98.73 ± 1.46d	281.29 ± 6.10c	353.31 ± 8.50f	360.37 ± 8.60f	323.68 ± 9.63f	275.72 ± 9.96f
PGP1	14.03 ± 0.23b	68.37 ± 1.35d	96.01 ± 1.92 cd	99.88 ± 1.44 cd	100.47 ± 1.69 cd	300.71 ± 6.91b	382.85 ± 9.95e	397.23 ± 11.2e	362.20 ± 10.99e	327.08 ± 11.38e
PGP2	13.92 ± 0.26b	70.77 ± 1.48ab	98.94 ± 1.92ab	103.54 ± 1.54ab	104.10 ± 1.52ab	304.38 ± 6.87b	434.67 ± 9.10b	456.57 ± 9.74b	430.80 ± 9.61b	405.02 ± 10.10b
PGP3	14.50 ± 0.21a	68.90 ± 1.39bcd	97.13 ± 2.07bcd	101.21 ± 1.63bc	101.79 ± 1.66bc	299.90 ± 6.07b	398.01 ± 9.45d	416.15 ± 10.3d	384.92 ± 10.08d	353.04 ± 11.13d
PGP4	14.18 ± 0.28ab	70.19 ± 1.40abc	98.38 ± 1.89abc	102.74 ± 1.67ab	103.31 ± 1.42ab	315.66 ± 6.44a	421.96 ± 7.59c	441.49 ± 8.37c	413.81 ± 9.02c	384.27 ± 9.30c
PGP5	14.06 ± 0.24b	71.42 ± 1.38a	100.52 ± 1.84a	105.37 ± 1.43a	105.91 ± 1.48a	301.46 ± 4.25b	447.02 ± 9.17a	474.11 ± 10.2a	451.69 ± 10.8a	430.88 ± 11.13a
SEm±	0.056	0.242	0.326	0.341	0.355	1.030	1.249	1.621	1.691	1.356
LSD (≤0.05)	0.162	0.707	0.952	0.994	1.036	3.005	3.644	4.732	4.936	3.957

K-607 has the shortest plants. Amongst various plant growth promoters (Table 2), PGP_5 (chelated micronutrient: Zn, Fe, Cu, Mn) treated plants were the tallest and PGP_2 and PGP_4 treated plants had similar growth was in PGP_0 (control) treated plants were the shortest. The maximum tillers and TPR occurred in DBW-187 followed by K-1006 and the minimum in K-607. Among plant growth promoters, plants treated with chelated micronutrient (PGP_5) exhibited maximum tiller and TPR, PGP_2 and PGP_4 treated plants had significantly similar tillers and TPR and minimum in PGP_0. The tillers increment was recorded in PGP_5, PGP_2 and PGP_4 treated plants over PGP_0 (Table 2, and 3).

Effect on Crop Growth Indices

Among the wheat genotypes, DBW-187 demonstrated the highest DMA and LAI, and K-107 recorded the lowest. Among the PGPs, chelated micronutrient (PGP_5) treated plants exhibited the greatest DMA and LAI, PGP_2 and PGP_4 treated plants showed comparable results, and PGP_0 treated plants had the lowest values (Table 4, and 5). DMA was increase significant increased at harvest in PGP_5, PGP_2, and PGP_4 treated plants, compared to PGP_0 (Table 2). The LAI at flowering increased in PGP_5, PGP_2, and PGP_4 treated plants, compared to PGP_0 (Table 5).

Genotypes and PGPs significantly affected growth indices, including (i) crop growth rate (CGR), (ii) relative growth rate (RGR), and (iii) net assimilation rate (NAR) across all wheat growth stages (Table 4, and 5). DBW-187, and PGPs, particularly PGP_5 (chelated micronutrients) treated plants had, the highest CGR, RGR, and NAR during all growth phases of wheat (Table 4, and 5). During the initial growth phase (0 to 30 DAS), the genotype DBW-187 exhibited greater CGR, RGR, and NAR, compared to K-607. During the 30–60 DAS and 60–90 DAS phases, DBW-187 showed significantly higher CGR, RGR, and NAR, compared to K-607 (Table 4, and 5). However, among the PGPs options, the application of PGP_5 (chelated micronutrients) resulted in the highest CGR, RGR, and NAR across all growth phases of wheat. During the initial growth phase (0 to 30 DAS), PGP_3 (seaweed extract granules) exhibited significantly higher CGR, RGR, and NAR, compared to K-607 (Table 4, and 5). In the 30–60 DAS and 60–90 DAS phases, PGP_5 treatment (chelated micronutrients) significantly increased CGR, RGR, and NAR, compared to PGP_0 (control).

Effect on Physiological Indicators

Wheat genotypes and PGPs treatment on chlorophyll content (SPAD) and canopy vigor (NDVI), revealing significant genotype × PGPs interactions at all stages (Table 6; Figs. 4a-b and 5a-b). DBW-187 consistently outperformed K-1006 and K-607 in both SPAD and NDVI measurements throughout the growth period. DBW-187 exhibited the highest values at each stage, reflecting greater chlorophyll retention and canopy vigor, while K-607 recorded the lowest, indicating reduced photosynthetic capacity and vegetative health (Figs. 4a-b and 5a-b). The application of PGPs revealed distinct trends in enhancing SPAD and NDVI values compared to the control (PGP_0), which consistently exhibited the lowest measurements across all stages, indicative of limited chlorophyll synthesis and canopy development without PGPs intervention.

PGP_5 (chelated micronutrients) and PGP_2 (gibberellic acid) treatments had the most pronounced effects, achieving the highest SPAD and NDVI values, particularly from 60 DAS through flowering (Figs. 6a-b). Results suggested their superior efficacy in sustaining photosynthetic efficiency and canopy vigor during critical reproductive phases. PGP_3 (seaweed extract granules) treatment showed an early advantage, peaking at 30 DAS for both parameters, while PGP_4 (seaweed extract liquid) and PGP_1 (nitrobenzene) yielded intermediate improvements, compared to PGP_0 but less than PGP_5 and PGP_2 treatments in later stages (Table 6). Across all treatments, both SPAD and NDVI values followed an upward trend from 30 DAS to flowering, with the steepest increases occurring between 30 and 60 DAS, reflecting rapid vegetative growth and chlorophyll accumulation (Figs. 5a-b). Genotype G_1, when combined with PGP_5 or PGP_2, exhibited the most consistent and robust enhancement, underscoring the synergistic potential of high-yielding genotypes and targeted PGP applications (Table 6).

Interaction effects of wheat genotypes and PGPs on stomatal conductance were significant across all stages (Table 4). DBW-187 (G_1) consistently exhibited the highest stomatal conductance throughout the growth period (Table 6). This trend reflected G_1 superior capacity for gas exchange, likely contributing to enhanced photosynthetic rates and water use efficiency (WUE). G_2 displayed intermediate values, while G_3 had the lowest conductance, suggesting a gradient in physiological performance among the genotypes. The application of PGPs significantly influenced stomatal conductance, with the control (PGP_0) consistently yielding the lowest values across all stages, indicative of limited stomatal regulation without growth promoter support. Among the PGPs treatments, PGP_2 (gibberellic acid) and PGP_5 (chelated micronutrients) demonstrated the most pronounced effects, particularly at 60 DAS, 90 DAS, and flowering, where they elicited the highest conductance levels (Table 6). This suggests their efficacy in sustaining stomatal opening and facilitating CO_2-uptake during critical growth phases.

Table 2 TEffect of wheat genotypes and plant growth promoters on tiller production rate and dry matter accumulation of spring wheat (mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

Treatments	Tiller Production rate (tillers m^{-2} day^{-1})					Dry matter accumulation (g m^{-2})				
	0 to CRI	CRI to Tillering	Tillering to flowering	Flowering to ripening	Ripening to Harvest	CRI	Tillering	Flowering	Ripening	Harvest
Genotypes										
G1	10.65±0.10a	3.85±0.23a	0.68±0.05a	0.96±0.03a	1.63±0.11a	43.19±0.44a	304.57±8.52a	1052.02±32.7a	1319.16±42.2a	1365.56±45.8a
G2	10.04±0.11b	3.62±0.22b	0.59±0.05b	0.99±0.04b	1.77±0.11b	41.87±0.52b	289.11±7.93b	963.10±30.94b	1220.16±38.9b	1261.82±42.10b
G3	9.35±0.12c	3.09±0.17c	0.53±0.05c	1.02±0.05c	1.90±0.12c	39.78±0.45c	262.42±6.39c	842.75±26.6c	1079.93±32.6c	1115.54±34.80c
SEm±	0.016	0.005	0.002	0.001	0.002	0.057	0.217	1.208	1.178	2.828
LSD (≤0.05)	0.062	0.020	0.006	0.005	0.008	0.223	0.853	4.743	4.626	11.105
Plant growth promoters (PGPs)										
PGP0	9.37±0.21c	2.40±0.08f	0.23±0.01f	1.22±0.02f	2.66±0.05f	38.65±0.43d	234.72±4.74e	751.67±22.4f	955.84±24.5f	981.24±25.7f
PGP1	10.02±0.22b	2.73±0.11e	0.47±0.03e	1.16±0.01e	1.95±0.05e	41.18±0.38c	254.85±4.30d	832.08±24.1e	1054.49±27.1e	1084.71±27.3e
PGP2	10.14±0.24b	4.34±0.08b	0.73±0.01b	0.85±0.01b	1.44±0.03b	41.55±0.60bc	309.84±7.39b	1053.25±31.8b	1334.35±36.4b	1387.51±40.1b
PGP3	9.99±0.20b	3.27±0.11d	0.60±0.03d	1.04±0.01d	1.77±0.04d	43.92±0.52a	287.20±6.94c	954.29±32.1d	1204.21±36.7d	1240.27±38.7d
PGP4	10.52±0.21a	3.54±0.06c	0.65±0.03c	0.92±0.01c	1.64±0.03c	41.91±0.82bc	301.29±7.40b	1010.90±35.3c	1276.95±41.2c	1317.57±42.1c
PGP5	10.04±0.16b	4.85±0.26a	0.90±0.03a	0.74±0.01a	1.15±0.04a	42.46±0.84b	324.31±7.53a	1113.55±31.2a	1412.66±39.20a	1474.54±42.3a
SEm±	0.036	0.014	0.002	0.003	0.007	0.141	1.196	3.344	4.654	5.020
LSD (≤0.05)	0.105	0.041	0.005	0.009	0.019	0.411	3.492	9.760	13.585	14.654

Effect on Chlorophyll and Carotenoid

Pooled data over two years showed that wheat genotypes and PGPs significantly affected chlorophyll and carotenoid contents (Table 7). At 30 DAS, genotype DBW-187 (G1) exhibited the highest levels of chlorophyll a, b, a: b ratio, total chlorophyll, and carotenoids compared to K-1006 and K-607. PGP3 (seaweed extract granules) application resulted in higher chlorophyll a, b, the a: b ratio, total chlorophyll, and carotenoid content in fresh wheat leaves compared to PGP_0 (control) (Table 7). At 60 DAS and the flowering stage, the wheat genotype DBW-187 exhibited higher levels of chlorophyll a, b, the a: b ratio, total chlorophyll, and carotenoids compared to K-1006 and K-607 (Table 7). PGP_5 (chelated micronutrients) treated plants had the highest chlorophyll a, b, the a: b ratio, total chlorophyll, and carotenoid content in fresh wheat leaves, PGP_2 and PGP_4 treatments being statistically similar, while PGP_0 showed the lowest values (Table 7).

Effect on Yield and Yield Components

Two-year pooled data (Table 7) showed that genotypes and PGPs significantly influenced yield and its components in spring wheat. The genotype DBW-187 (G_1) demonstrated significantly higher spikes m^{-2}, spike length, grains per spike, grain weight per spike, test weight, and fertility index, compared to K-607. PGP_5 (chelated micronutrient) treatment elicited the highest increases in these parameters, compared to PGP_0 (control). Similarly, PGP_2 and PGP_4 treatments had similar results (Table 7). DBW-187 recorded the highest grain, straw, biological yield, and harvest index, compared to K-607 (Table 7). PGP_5 (chelated micronutrient) treatment resulted in the highest grain, straw, biological yield, and harvest index, compared to PGP_0 (control), PGP_2 and PGP_4 treatments showed similar performance (Table 7).

Effect on Production and Economic Efficiency

The production and economic efficiency of wheat were significantly affected by genotype and PGPs options. The highest production efficiency (PE) and economic efficiency (EE) was in G_2, followed by G_1 and lowest in G_3 (Figs. 6a and 7a). PE and EE of wheat were significantly affected by PGPs treatments (Figs. 6b and 7b). PGP_5 treatment had the highest PE value, equal to that of G_2. PGP_2 treated plants had a high PE and the lowest PE was recorded in PGP_0, followed by PGP_1. Similarly, the highest EE among PGPs treated plants was with PGP_5 followed by PGP_2, PGP_3 and the lowest EE was in PGP_1 treated plants (Fig. 7b).

Table 3 Effect of wheat genotypes and plant growth promoters on crop growth (CGR) and relative growth rate (RGR) of spring wheat (mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

Treatments	CGR ($g\ m^{-2}\ day^{-1}$)					RGR ($mg\ g^{-1}\ day^{-1}$)				
	0 to CRI	CRI to Tillering	Tillering to flowering	Flowering to ripening	Ripening to Harvest	0 to CRI	CRI to Tillering	Tillering to flowering	Flowering to ripening	Ripening to Harvest
Genotypes										
G1	1.43±0.02a	8.71±0.27a	24.91±0.80a	8.90±0.33a	2.57±0.19a	54.50±0.36a	28.18±0.35a	17.91±0.12a	3.60±0.02a	0.81±0.04a
G2	1.39±0.02b	8.24±0.25b	22.46±0.78b	8.56±0.26b	2.31±0.17b	54.04±0.34a	27.89±0.32a	17.37±0.12ab	3.42±0.03b	0.79±0.03a
G3	1.32±0.02c	7.42±0.21c	19.34±0.67c	7.90±0.20c	1.97±0.14c	53.31±0.31a	27.24±0.39b	16.83±0.13b	3.26±0.03c	0.76±0.03b
SEm±	0.001	0.009	0.053	0.015	0.005	0.088	0.023	0.041	0.004	0.002
LSD (≤0.05)	0.005	0.034	0.207	0.060	0.018	0.344	0.090	0.162	0.015	0.006
Plant growth promoters (PGPs)										
PGP0	1.28±0.02d	6.53±0.13f	17.23±0.61f	6.80±0.07f	1.41±0.05f	52.90±0.47b	26.09±0.34d	16.8±0.25d	3.49±0.08a	0.63±0.01f
PGP1	1.37±0.01c	7.12±0.13e	19.24±0.68e	7.41±0.08e	1.67±0.06e	53.82±0.34ab	26.37±0.16 cd	17.09±0.23 cd	3.44±0.07ab	0.68±0.01e
PGP2	1.38±0.02bc	8.94±0.22b	24.78±0.82b	9.36±0.21b	2.95±0.10b	53.94±0.41ab	29.06±0.28ab	17.68±0.12ab	3.43±0.04ab	0.94±0.02b
PGP3	1.46±0.01a	8.10±0.22d	22.23±0.85d	8.33±0.15d	2.00±0.07d	54.75±0.53a	27.15±0.35c	17.34±0.18bc	3.38±0.06b	0.71±0.01d
PGP4	1.39±0.03bc	8.64±0.21c	23.65±0.91c	8.86±0.19c	2.25±0.09c	54.05±0.53ab	28.53±0.26b	17.48±0.21abc	3.39±0.05b	0.75±0.02c
PGP5	1.41±0.03b	9.39±0.21a	26.30±0.82a	9.97±0.26a	3.43±0.13a	54.24±0.54ab	29.42±0.28a	17.83±0.17a	3.44±0.03ab	1.03±0.01a
SEm±	0.005	0.026	0.076	0.030	0.010	0.200	0.110	0.051	0.012	0.002
LSD (≤0.05)	0.015	0.076	0.221	0.089	0.030	0.584	0.321	0.149	0.036	0.007

Correlation Coefficients Matrix

The correlation coefficient matrix (Figs. 8a-b) showed significant positive correlations (***$p<0.001$, **$p<0.01$, *$p<0.05$) among all wheat traits across genotypes and plant growth promoters over both years. Overall results indicated that plant height at harvest (PPH), tillers at harvest (TH), dry matter accumulation at harvest (DMAH), crop growth rate (CGRF), relative growth rate (RGRF), net assimilation rate (NARF), leaf area index at flowering (LAIF), SPAD at flowering, NDVI at flowering, stomatal conductance at flowering (SCF), chlorophyll a + b at flowering (Ch1 + bF), spikes m^{-2} (SM), spike length (LOS), grains $spike^{-1}$ (GPS), test weight (TW), fertility index (FI), grain yield (GY), straw yield (SY), biological yield (BY), and harvest index (HI) were all significantly and positively correlated with TH, DMAH, CGRF, RGRF, NARF, LAIF, SPAD, NDVI, SCF, Ch1 + bF, SM, LOS, GPS, FI, GY, SY, BY, and HI. DMAH showed a highly significant positive correlation (*** = $p<0.001$) with stomatal conductance at flowering ($r=0.90$*** and $r=0.90$***), chlorophyll a + b at flowering ($r=0.90$*** and $r=0.90$***), grain yield ($r=0.94$*** and $r=0.93$***), and biological yield ($r=0.90$*** and $r=0.85$***) across both years, respectively (Figs. 8a-b). LAIF also exhibited a highly significant positive correlation with stomatal conductance ($r=0.81$*** and $r=0.80$***), spikes m^{-2} ($r=0.80$*** and $r=0.82$***), grain yield ($r=0.79$*** and $r=0.82$***), and biological yield ($r=0.82$*** and $r=0.86$***) during both years, respectively. A significant positive correlation was found between yield attributes, such as spikes m^{-2}, and both grain yield ($r=0.83$*** and $r=0.85$***) and biological yield ($r=0.86$*** and $r=0.86$***) across both years, respectively (Figs. 8a-b).

Discussion

Growth Parameters

The genotypes of wheat and PGPs (plant growth promoters) play a crucial role in enhancing growth, resistance to biotic and abiotic stresses, and the productivity of spring wheat (Layek et al. 2018; Benítez García et al. 2020; Dhaliwal et al. 2022; Meena et al. 2026a, b). The wheat genotype DBW-187 exhibited significantly higher growth parameters such as plant height, tillers, dry matter accumulation, and leaf area index, compared to the other wheat genotypes (Tables 2, 3, 4 and 5). The variation between wheat genotypes yields potential and responses to inputs (plant nutrients) offers an agronomist the opportunity to select wheat genotypes. The use of PGPs further enhances N absorption and yield potential, supporting breeding progress and yield improvements

Table 4 Effect of wheat genotypes and plant growth promoters on net assimilation rate (NAR) and leaf area index (LAI) of spring wheat (mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

Treatments	NAR (mg m^{-2} leaf area day^{-1})				Leaf area index			
	0 to CRI	CRI to Tillering	Tillering to flowering	Flowering to ripening	CRI	Tillering	Pre-flowering	Post-flowering
Genotypes								
G1	58.02±4.58b	1988.80±55.5a	2747.62±69.2a	1469.78±41.6a	1.11±0.01b	2.99±0.03a	5.06±0.05a	5.50±0.06a
G2	65.80±3.21a	1857.89±53.0b	2459.00±73.3b	1430.36±32.5b	1.13±0.01a	3.02±0.02a	5.02±0.02a	5.45±0.05a
G3	58.29±4.36b	1748.40±41.2c	2305.06±59.6c	1405.60±19.2b	1.12±0.01ab	2.81±0.02b	4.59±0.07b	4.99±0.08b
SEm±	0.166	1.105	4.627	1.686	0.001	0.004	0.006	0.005
LSD (≤0.05)	0.653	4.340	18.168	6.619	0.005	0.016	0.022	0.020
Plant growth promoters (PGPs)								
PGP0	42.94±0.84e	1550.14±28.7e	2049.61±49.5e	1244.02±16.3e	1.08±0.01c	2.85±0.02d	4.56±0.09d	4.96±0.11d
PGP1	60.58±5.19c	1653.67±26.9d	2226.61±68.0d	1300.93±18.6d	1.12±0.01ab	2.89±0.05 cd	4.75±0.08c	5.16±0.09c
PGP2	65.95±6.04b	2024.56±50.3b	2709.40±67.3b	1522.71±21.5b	1.13±0.02a	2.99±0.04ab	5.12±0.05a	5.56±0.06a
PGP3	76.36±6.46a	1861.59±35.2c	2561.89±72.6c	1451.16±19.8c	1.14±0.02a	2.89±0.06 cd	4.79±0.10c	5.20±0.11c
PGP4	65.07±4.73b	1973.20±45.9b	2641.27±72.4bc	1487.18±13.1bc	1.13±0.01a	2.96±0.05bc	4.96±0.09b	5.39±0.10b
PGP5	53.33±2.88d	2127.02±40.8a	2834.60±66.4a	1605.50±32.0a	1.10±0.01bc	3.06±0.03a	5.16±0.06a	5.61±0.08a
SEm±	0.264	7.271	10.586	5.371	0.004	0.010	0.016	0.021
LSD (≤0.05)	0.769	21.223	30.898	15.678	0.011	0.029	0.046	0.062

Table 5 Effect of genotypes and plant growth promoters on Stomatal conductance, Chlorophyll and Carotenoids of spring wheat (Mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

Treatments	Stomatal conductance (mmol m^{-2} sec^{-1})				Chlorophyll and Carotenoids (mg g^{-1}) at CRI				
	CRI	Tillering	Pre-flowering	Post-flowering	Chl. a	Chl. b	Chl. a: b	Chl. ab	Carotenoids
Genotypes									
G1	134.11±2.41a	184.16±2.69a	168.04±2.44a	157.47±2.244a	2.29±0.05a	1.17±0.02a	1.99±0.02a	3.47±0.07a	0.67±0.03a
G2	129.93±2.88b	176.66±3.06b	161.35±2.84b	151.18±2.60b	2.18±0.06b	1.08±0.02b	1.94±0.02a	3.26±0.08b	0.64±0.03b
G3	122.63±2.70c	166.66±3.64c	152.42±3.27c	142.78±3.08c	1.98±0.08c	1.06±0.02c	1.84±0.03b	3.04±0.10c	0.62±0.03b
SEm±	0.221	0.200	0.210	0.137	0.002	0.001	0.005	0.005	0.001
LSD (≤0.05)	0.869	0.784	0.825	0.537	0.007	0.005	0.020	0.021	0.005
Plant growth promoters (PGPs)									
PGP_0	109.70±2.34e	151.16±3.79e	138.58±3.36d	129.77±3.06e	1.72±0.06f	0.95±0.02f	1.80±0.04e	2.68±0.08f	0.49±0.02e
PGP_1	122.46±1.86d	170.16±2.74d	155.54±2.88c	145.72±2.24d	1.95±0.06e	1.05±0.02e	1.85±0.04d	3.00±0.08e	0.56±0.01d
PGP_2	135.54±2.12b	186.16±2.12b	169.83±1.96a	159.15±1.95b	2.36±0.04b	1.18±0.02b	2.00±0.04b	3.54±0.05b	0.69±0.01b
PGP_3	143.25±2.28a	176.50±2.42c	161.20±2.25b	151.04±2.35c	2.50±0.03a	1.21±0.02a	2.15±0.05a	3.72±0.04a	0.85±0.01a
PGP_4	132.36±2.03bc	180.16±2.62c	164.47±2.42b	154.11±2.20c	2.22±0.05c	1.14±0.02c	1.94±0.02c	3.37±0.07c	0.67±0.01b
PGP_5	130.00±1.80c	190.83±2.08a	174.00±2.06a	163.07±1.78a	2.13±0.05d	1.11±0.02d	1.91±0.03c	3.24±0.07d	0.60±0.01c
SEm±	0.559	0.513	0.609	0.464	0.009	0.004	0.006	0.011	0.003
LSD (≤0.05)	1.633	1.497	1.776	1.355	0.027	0.012	0.018	0.033	0.008

(Gawdiya et al. 2023a). Genotype specific N application combined with plant growth promoters, increased yield, and harvest index (HI), N uptake, and partial N balance. DMA, plant height, spike size, tillering capacity in wheat cultivars varies due to genotypic diversity affecting photo-assimilate distribution to reproductive organs (Gawdiya et al. 2023b). Proper scheduling of irrigation and nitrogen application, along with the adoption of genotypes suited to specific environments, significantly enhances growth, grain yield, NUE and WUE (Zhiipao et al. 2023; Meena et al. 2026a, b).

Bio-fortification is a key agricultural strategy to enhance micronutrient concentrations in grains and reduce malnutrition. Foliar application of Zn (0.5% $ZnSO_4$) and Fe (1% $FeSO_4$) improved wheat yield traits and grain quality (Nayak et al. 2023). Intensive cropping and fertilizer use are increasing micronutrient-deficient soils (Dhaliwal et al. 2022). Fe supports chlorophyll synthesis and electron

Table 6 Effect of genotypes and plant growth promoters on chlorophyll and carotenoids of spring wheat (Mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

Treatments	Chlorophyll and Carotenoids (mg g_{-1}) at Tillering					Chlorophyll and Carotenoids (mg g_{-1}) at Flowering				
	Chl. a	Chl. b	Chl. a: b	Chl. ab	Carotenoids	Chl. a	Chl. b	Chl. a: b	Chl. ab	Carotenoids
Genotypes										
G1	3.82±0.11a	2.07±0.04a	1.84±0.02a	5.89±0.05a	1.16±0.04a	3.30±0.07a	1.94±0.04a	2.00±0.05a	4.95±0.08a	1.44±0.09a
G2	3.51±0.11b	1.90±0.04b	1.84±0.02a	5.41±0.05b	1.09±0.04b	3.16±0.08b	1.86±0.04b	1.92±0.05b	4.81±0.08b	1.35±0.08b
G3	3.36±0.11c	1.85±0.04c	1.80±0.02a	5.21±0.05c	1.04±0.04c	3.10±0.07b	1.84±0.04b	1.88±0.05b	4.76±0.08b	1.31±0.08c
SEm±	0.005	0.001	0.004	0.010	0.002	0.005	0.004	0.002	0.007	0.002
LSD (≤0.05)	0.022	0.004	0.014	0.040	0.007	0.019	0.015	0.010	0.029	0.006
Plant growth promoters (PGPs)										
PGP0	2.81±0.06e	1.64±0.03e	1.71±0.01b	4.45±0.10f	0.83±0.02f	2.62±0.04f	1.59±0.02e	1.59±0.02e	4.27±0.04e	0.84±0.02f
PGP1	3.09±0.06d	1.76±0.03d	1.75±0.01b	4.86±0.09e	0.92±0.02e	2.98±0.03e	1.77±0.02d	1.81±0.02d	4.63±0.05d	1.05±0.02e
PGP2	3.98±0.08a	2.10±0.04a	1.88±0.02a	6.08±0.10b	1.24±0.02b	3.44±0.05b	2.00±0.02b	2.09±0.02b	5.09±0.05ab	1.65±0.04b
PGP3	3.64±0.08c	1.95±0.04c	1.86±0.02a	5.59±0.10d	1.12±0.01d	3.21±0.04d	1.89±0.02c	1.95±0.02c	4.86±0.06c	1.32±0.02d
PGP4	3.79±0.07b	2.02±0.03b	1.87±0.01a	5.81±0.11c	1.18±0.01c	3.32±0.03c	1.95±0.02bc	2.01±0.02bc	4.97±0.06bc	1.52±0.02c
PGP5	4.09±0.07a	2.15±0.03a	1.90±0.01a	6.24±0.10a	1.31±0.02a	3.57±0.04a	2.07±0.02a	2.16±0.03a	5.22±0.05a	1.83±0.04a
SEm±	0.016	0.007	0.007	0.018	0.004	0.005	0.004	0.002	0.007	0.002
LSD (≤0.05)	0.047	0.020	0.020	0.051	0.013	0.019	0.015	0.010	0.029	0.006

transport, with deficiency impairing enzyme activity and Fe uptake. Plants mitigate nutrient imbalances by reducing leaf area and adjusting osmotically through seaweed extract, organic compounds, and minerals (Nadeem and Farooq 2019).

Physiological Traits

Physiological traits play a crucial role in determining wheat yield and its components (Figs. 4a-b and 5a-b). Higher NDVI and SPAD values reflect better photosynthetic efficiency and biomass accumulation. Stomatal conductance influences WUE and gas exchange, affecting grain filling. Chlorophyll content is directly linked to photosynthetic activity, while carotenoids protect against oxidative stress. Together, these traits contribute to improved grain number, size, and overall wheat productivity (Yengoh et al. 2015). The observed trends in SPAD and NDVI values across wheat genotypes and PGPs treatments used in the present study underscore the significant influence of genetic variation and exogenous PGPs on chlorophyll content and canopy vigor, key indicators of photosynthetic capacity and plant health (Figs. 5a-b). Among the genotypes, DBW-187 consistently exhibited superior performance compared to K-1006 and K-607 confirming that is a high-yielding cultivar adapted to irrigated environments (Table 7). This genotypic advantage likely stems from enhanced chlorophyll synthesis and canopy development, which are critical for maximizing light interception and assimilating production during grain filling. Recent studies corroborate this, where wheat genotypes with higher chlorophyll retention under stress conditions exhibit greater yield stability, attributed to improved photosynthetic efficiency (Cao et al. 2024).

The application of PGPs, further amplified these genotypic differences, with chelated micronutrients (PGP_5) and gibberellic acid (PGP_2) eliciting the most substantial increases in SPAD and NDVI, particularly from tillering to post flowering (Figs. 5a-b). This enhancement reflects the role of micronutrients (Fe, Zn, Cu, Mn) in chlorophyll biosynthesis and enzyme activation, as well as gibberellic acid's promotion of cell elongation and leaf expansion, which collectively boost photosynthetic capacity (Wang et al. 2024; Lamlom et al. 2025; Amin et al. 2024; Azameti et al. 2024). This aligns with its known high-yielding traits under irrigated conditions, where optimized stomatal function supports greater assimilate production during grain filling (Zhang et al. 2025). The application of PGPs significantly modulated stomatal conductance, with the control (PGP_0) showing the lowest values across all stages, underscoring the baseline limitation of stomatal activity without supplemental inputs (Lamlom et al. 2025; Wang et al. 2024;

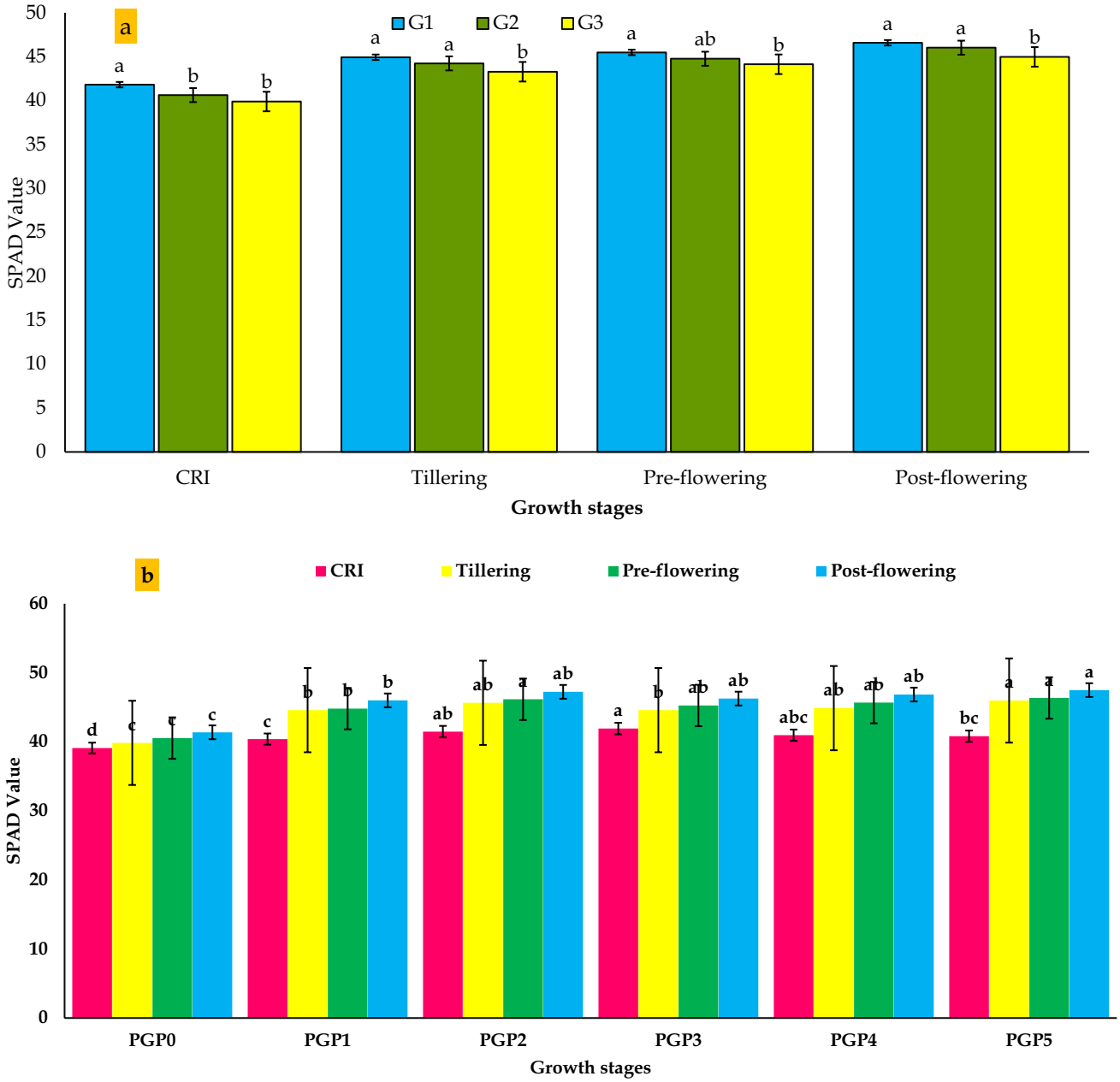


Fig. 4 (**a**) Effect of wheat genotypes on SPAD values across different growth stages (CRI, tillering, pre-flowering, and post-flowering). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3. (**b**) Effect of plant growth promoters (PGP) on SPAD value across different growth stages (CRI, tillering, pre-flowering, and post-flowering). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3

Amin et al. 2024; Shaddad et al. 2013; Chauhan et al. 2018; Meena and Meena 2017; Panday et al. 2018).

Yield Components and Yield

Genotypes and plant growth promoters play a significant role in determining wheat grain yield. Different genotypes respond differently to environmental conditions and input efficiency, which in turn influences their yield potential (Kasim et al. 2015; Meena et al. 2016a, b; Pazhanisamy et al. 2026). Among the genotypes, DBW-187 consistently demonstrated superior yield performance, compared to K-1006 and K-607 (Table 7). This superior performance reflects its increased capacity for CO_2-uptake and transpiration regulation, driven by higher DMA, LAI, chlorophyll, and carotenoid content, ultimately highlighting the genetic potential of the genotype and its response to inputs (Khan et al. 2009; Sobolewska et al. 2020; Panday et al., 2024). Chelated

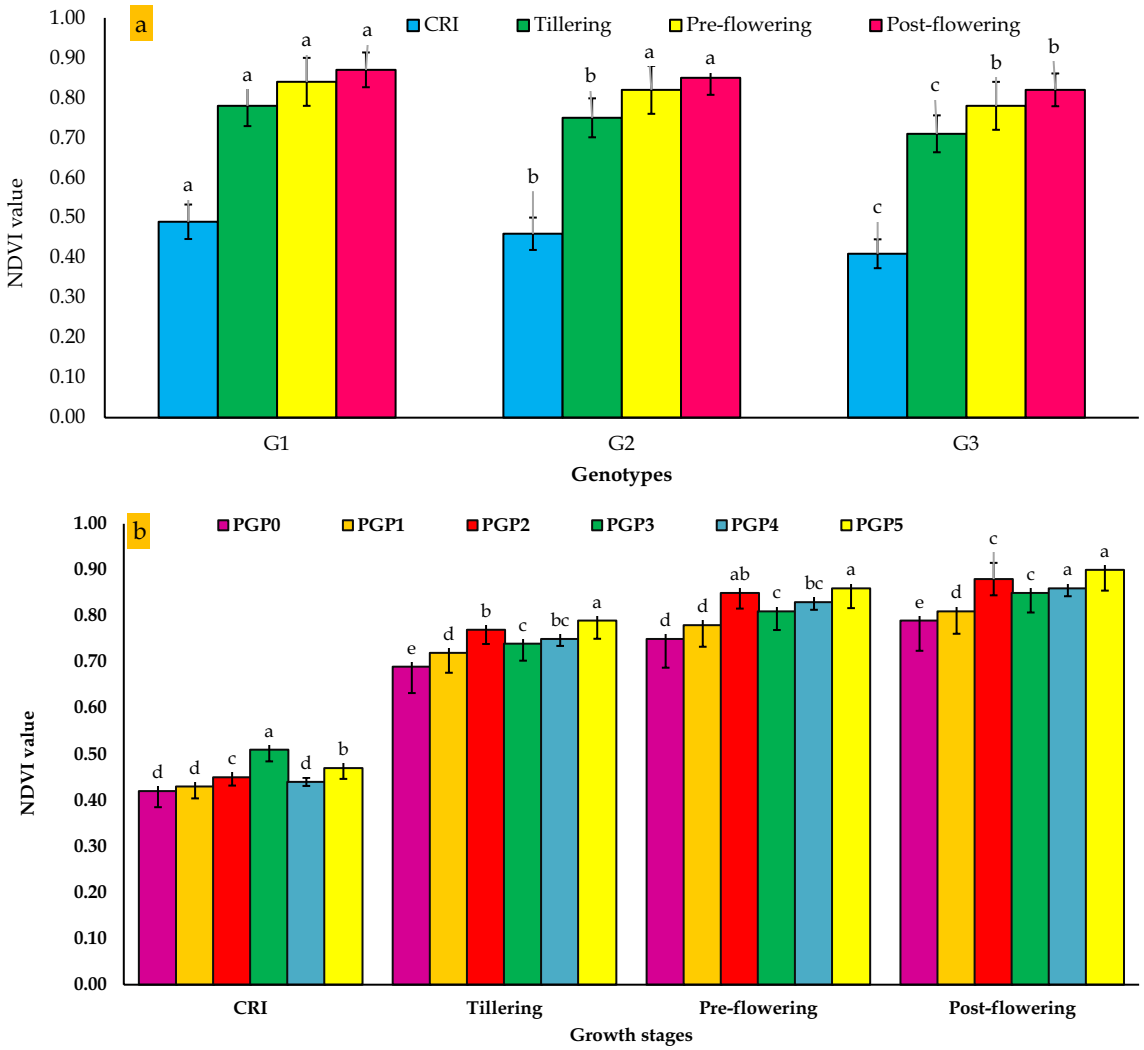
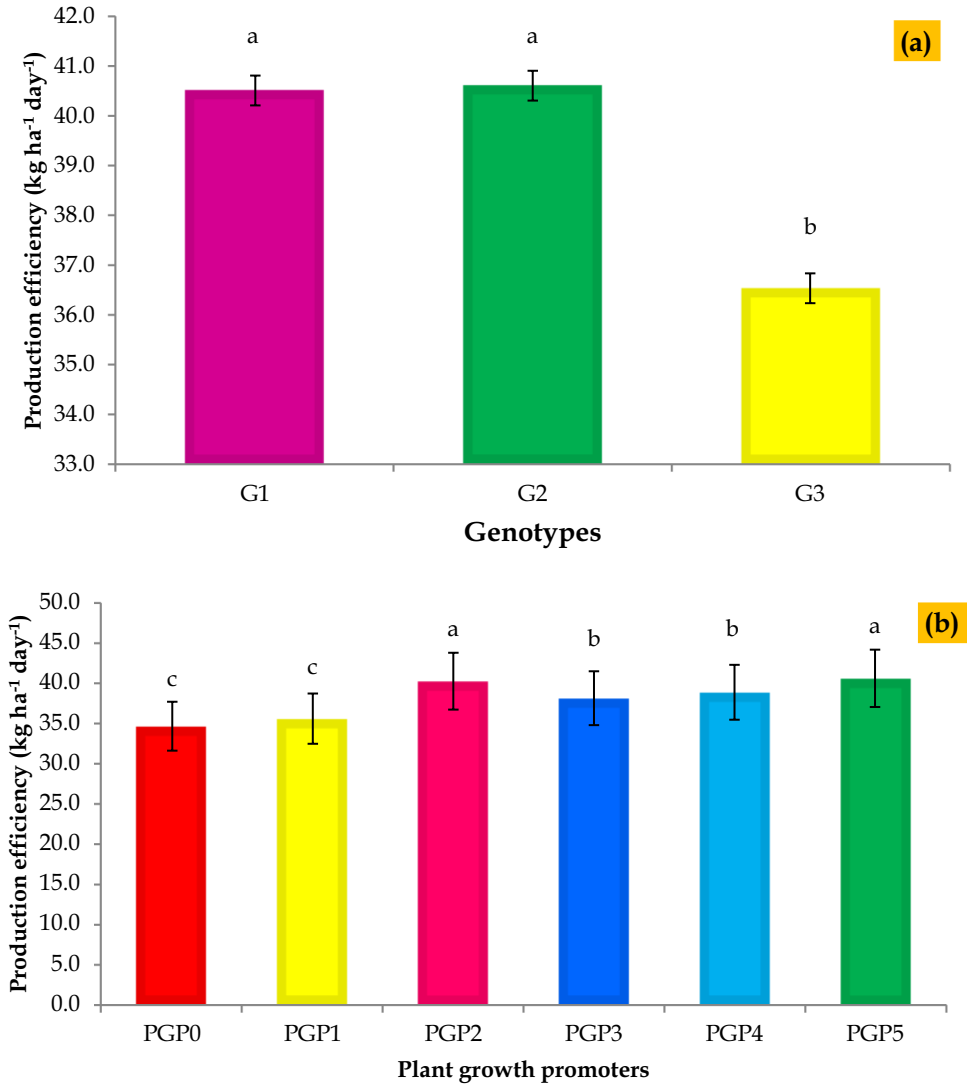


Fig. 5 (**a**) Effect of wheat genotypes on NDVI values across different growth stages (CRI, tillering, pre-flowering, and post-flowering). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3. (**b**) Effect of plant growth promoters (PGP) on NDVI value across different growth stages (CRI, tillering, pre-flowering, and post-flowering). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3

micronutrients application elicited the highest increases in grain, straw, biological yield, and harvest index, compared to PGP_0 (Table 7). Gibberellic acid (GA_3) stimulates cell elongation and division, leading to increased plant height and spikelet number. Seaweed extract improves nutrient uptake, stress tolerance, and hormonal balance, collectively boosting grain yield and quality (Khan et al. 2009; Sobolewska et al. 2020; Singh and Sidhu 2014). Understanding the dynamics of micronutrients (Zn, Fe, Cu, Mn) in relation to yield-trait relationships in crops offers an effective way to synchronize micronutrient demand and supply. This strategy improves nutrient management efficiency (fertilizer use), promotes sustainable production, and helps minimize environmental impact (Xue et al. 2014; Nadeem and Farooq 2019; Meena et al. 2016a, b). Imbalanced fertilizer use and the depletion of organic matter degrade soil structure, leading to reduced WUE and NUE (Meena et al. 2016a, b). Zinc (Zn), boron (B), and manganese (Mn) are crucial for metabolism, chlorophyll synthesis, and enzyme activation (Meena et al. 2015b). Their availability depends on soil properties, pH, moisture, and nutrient interactions under varying conditions. The application of micronutrients (Fe, Mn and Zn) significantly increases the plant growth, DMA, yield and yield components of wheat plants (Kumar et al. 2009), foliar fertilization of micronutrients (Zn Mn) has a significant impact on yield, yield components such as grain size, test weight, grains spike^{-1}, and spike length and overall yield of winter wheat (Sobolewska et al. 2020; Meena et al. 2015a, 2016a, b; Hafeez et al. 2021).



Figs. 6 (**a-b**) Effect on production efficiency of wheat (average of two years) as influenced by (a) genotype and (b) plant growth promoters (PGPs). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3

Seaweed extract boosts wheat growth, yield, and mineral content by improving resource use efficiency, soil water retention, and nutrient exchange, reducing chemical fertilizer reliance (Salim and Abdel-Rassoul 2016). Biostimulants support metabolism, photosynthesis, hormone production, chlorophyll and carotenoids content and nutrient absorption, promoting plant growth (Szczepanak et al. 2018); Singh et al. 2018; Bahrani and Pourreza 2012; Chowdhury et al. 2018; Wankhade et al. 2020; Cao et al. 2024). These pigments protect chlorophyll from oxidative stress, maintaining photosynthetic efficiency under abiotic stresses, thereby stabilizing wheat yield components like grain size and number (Chauhan et al. 2018).

Production and Economic Efficiency

The findings from the present study clearly demonstrate that both genotype and PGPs treatments significantly influence the PE and EE of wheat (Figs. 6a-b and 7a-b). Among the genotypes evaluated, G2 exhibited the highest production efficiency (PE), followed by G1, while G3 showed the lowest PE (Fig. 6a). In contrast, economic efficiency (EE) was highest in G1, followed by G2 and lowest in G3 (Fig. 7a). These findings suggest that genotype selection plays a critical role in optimizing both yield and profitability (Sarwar et al. 2024). Several studies highlight the significant benefits of adopting climate-smart and resource-conserving agricultural practices in the IGPs (Rashid et al. 2025). Improved crop establishment methods such as precision land leveling, raised bed planting, and conservation tillage have enhanced wheat productivity, profitability, and energy use efficiency (Jat et al. 2011; Kakraliya et al. 2018). The integration of optimal fertilizer management and sustainable intensification strategies reduces environmental footprints while maintaining high yields (Sapkota et al. 2020; Kumar et al. 2018). Additionally, combining plant growth promoters and improved genotypes with efficient crop management

Table 7 Effect of genotypes and plant growth promoters on yield attributes and yield of spring wheat (Mean of two years). Mean values (±SE) within a column followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3.

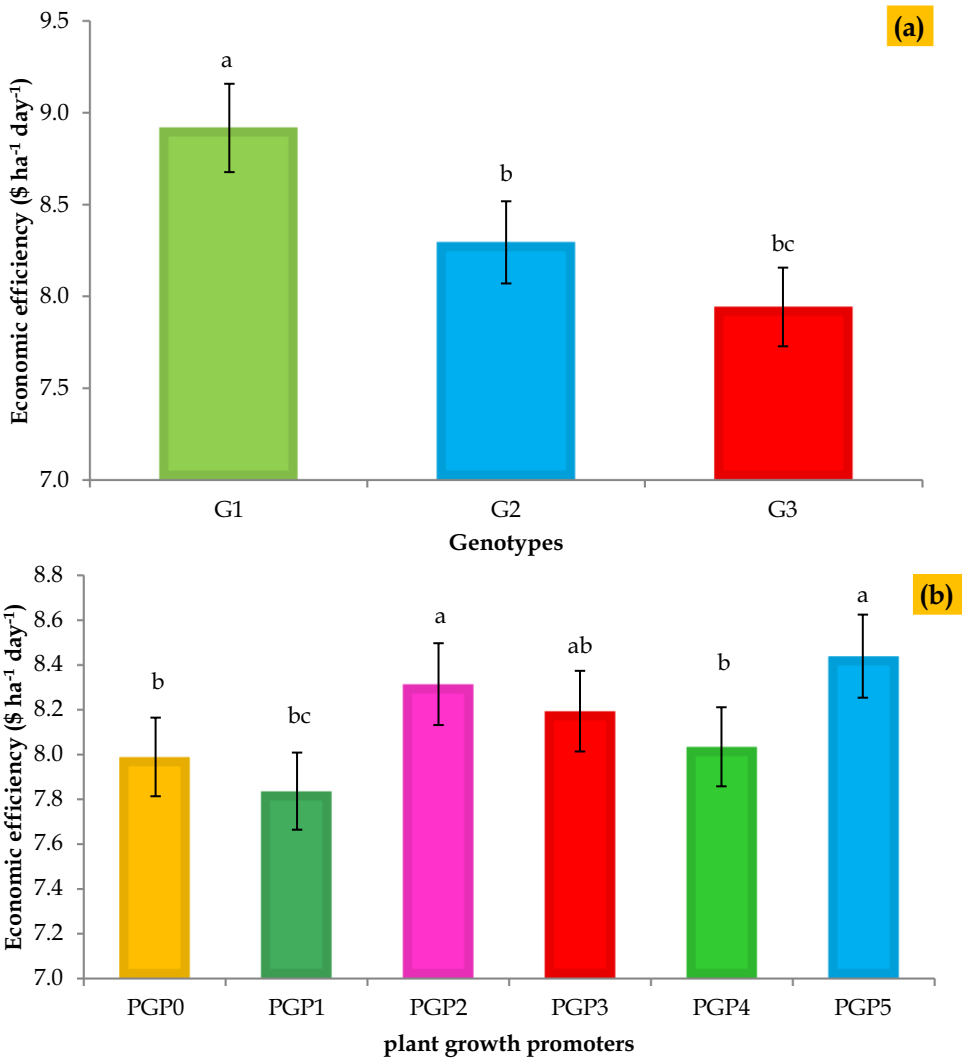
Treatments	Yield attributes						Yield (t ha^{-1})			Harvest index (%)
	Spikes m^{-2}	Length of spike (cm)	Grains spike^{-1}	Weight of grain spike^{-1}	TW (g)	Fertility index (%)	Grain Yield	Straw Yield	Biological Yield	
Genotypes										
G1	448.60±4.49a	16.85±0.30a	60.96±1.55a	2.69±0.06a	44.42±0.39a	92.79±1.42a	5.47±0.11a	7.40±0.08a	12.87±0.18a	42.43±0.39a
G2	439.03±5.14a	16.11±0.27b	55.51±1.30b	2.56±0.05b	43.18±0.36b	88.17±1.55ab	5.28±0.10b	7.25±0.07a	12.53±0.17b	42.07±0.37a
G3	411.82±5.23b	15.80±0.34b	53.15±1.72c	2.51±0.06c	41.95±0.37c	86.54±1.81b	4.75±0.06c	6.54±0.05b	11.29±0.11c	42.05±0.28a
SEm±	0.661	0.024	0.048	0.003	0.042	0.075	0.005	0.014	0.019	0.051
LSD (≤0.05)	2.596	0.094	0.187	0.011	0.164	0.293	0.019	0.055	0.076	0.199
Plant growth promoters (PGPs)										
PGP0	408.35±6.16d	14.04±0.26e	46.16±1.24f	2.19±0.03e	41.38±0.47b	76.75±0.64d	4.50±0.05f	6.68±0.11d	11.18±0.16e	40.25±0.34b
PGP1	416.79±5.59 cd	15.45±0.24d	52.06±1.44e	2.37±0.03d	42.93±0.55ab	82.47±0.94c	4.80±0.05e	6.87±0.11 cd	11.67±0.18d	41.14±0.50b
PGP2	449.92±6.28a	17.13±0.20b	62.02±1.08b	2.78±0.04b	43.77±0.58a	92.86±0.91a	5.47±0.12b	7.24±0.15ab	12.72±0.29b	43.02±0.37a
PGP3	428.76±6.52bc	16.48±0.10c	55.67±1.01d	2.60±0.03c	43.65±0.66a	86.71±1.04b	5.22±0.12d	7.05±0.14bc	12.28±0.25c	42.49±0.19a
PGP4	434.20±6.29b	16.76±0.18b	57.98±1.12c	2.70±0.04b	43.49±0.47a	88.93±0.90b	5.36±0.13c	7.15±0.14b	12.52±0.26bc	42.82±0.19a
PGP5	460.89±7.06a	17.65±0.27a	65.34±1.35a	2.88±0.04a	43.87±0.59a	95.27±1.07a	5.64±0.13a	7.37±0.16a	13.02±0.29a	43.35±0.35a
SEm±	1.639	0.060	0.184	0.010	0.205	0.388	0.014	0.025	0.036	0.158
LSD (≤0.05)	4.783	0.174	0.536	0.030	0.598	1.131	0.041	0.074	0.106	0.462

increases economic returns and resource use efficiency (Singh et al. 2020; Jat et al. 2020).

The correlation analysis revealed strong positive associations among key growth, physiological, and yield attributes, indicating their collective contribution to enhanced wheat performance under different genotypes and PGPs treatments (Sarwar et al. 2024; Sapkota et al. 2020). These relationships suggest that improvements in photosynthetic efficiency and biomass accumulation are closely linked to higher yield potential and overall productivity (Jat et al. 2011; Kakraliya et al. 2022).

Conclusion

This study establishes an integrated framework combining genotype selection with plant growth promoters (PGPs) to enhance wheat productivity, resource use efficiency, and sustainability in the central plain zone of India (Fig. 9). The integration of the high-yielding genotype DBW-187 with chelated micronutrient foliar spray (0.5%) consistently outperformed other treatment combinations, improving grain yield by 13–20%, straw yield by 9–12%, and production efficiency by ~15%. The combination also increased physiological efficiency, reflected in higher chlorophyll and carotenoid contents (up to 18%), stomatal conductance (~21%), and dry matter accumulation (~33%) compared with the control. Enhanced photosynthetic performance and nutrient utilization efficiency under this treatment contributed to a significant improvement in economic returns (~12%), confirming its agronomic and economic advantage. Overall, the synergistic interaction between genotype and PGPs, particularly DBW-187 with chelated micronutrients, demonstrates a viable and scalable strategy to rejuvenate productivity in the agr-food systems of the Indo-Gangetic Plains. This integrated approach strengthens crop resilience, improves soil-plant physiological functioning, and offers a sustainable pathway for increasing profitability under semi-arid and nutrient-stressed environments.



Figs. 7 (**a-b**) Effect on economic efficiency of wheat (average of two years) as influenced by (a) genotype and (b) plant growth promoters (PGPs). Mean values (±SE) on the bars followed by different letter(s) indicate significant differences at the 5% level according to the LSD test. Treatment details are provided in Fig. 3

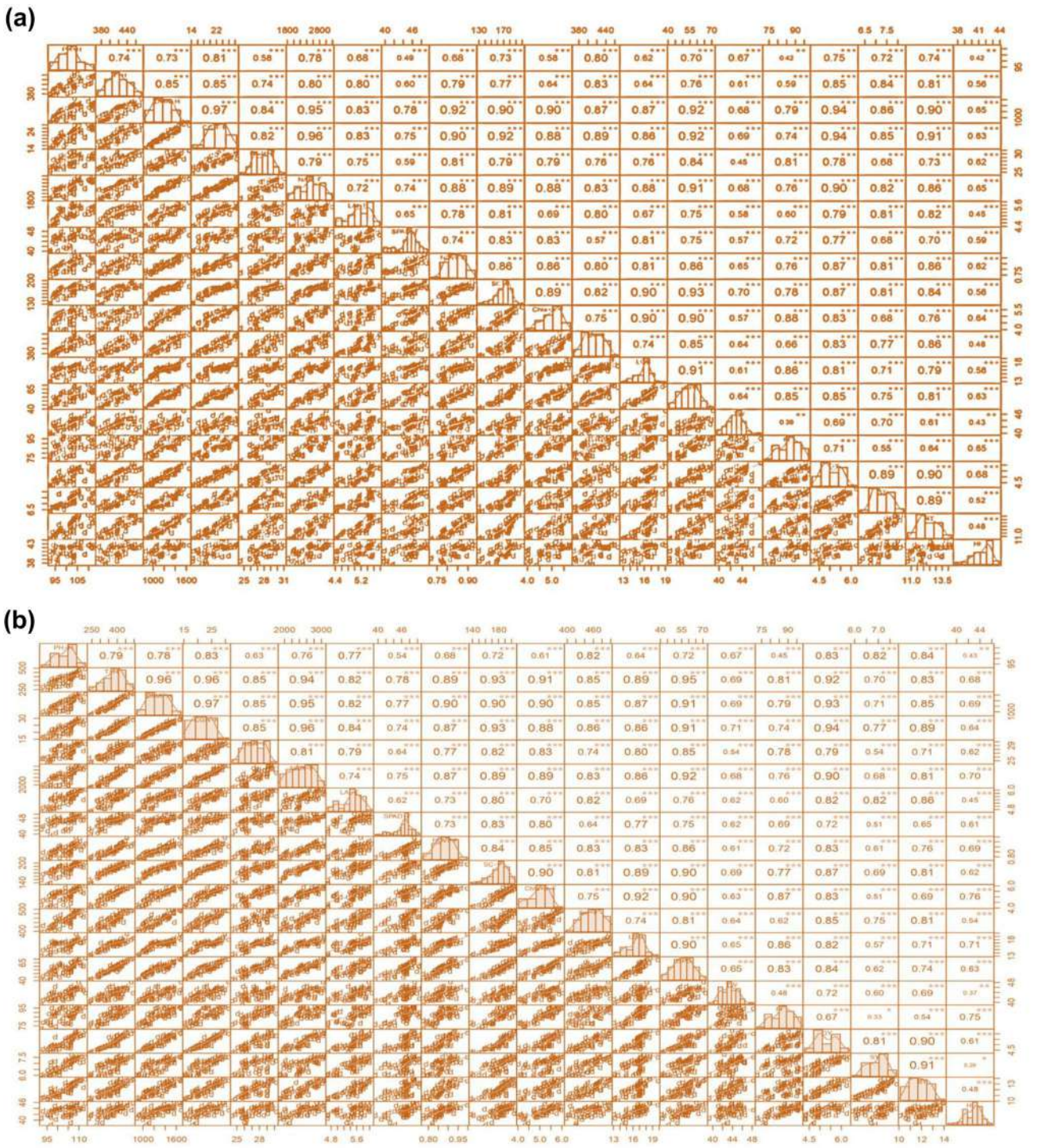


Fig. 8 (**a**) Pearson's correlation among crop physiological traits, yield and yield components of genotypes under plant growth promoters at 2021-22. (**b**) Pearson's correlation among crop physiological traits, yield and yield components of genotypes under plant growth promoters at 2022-23

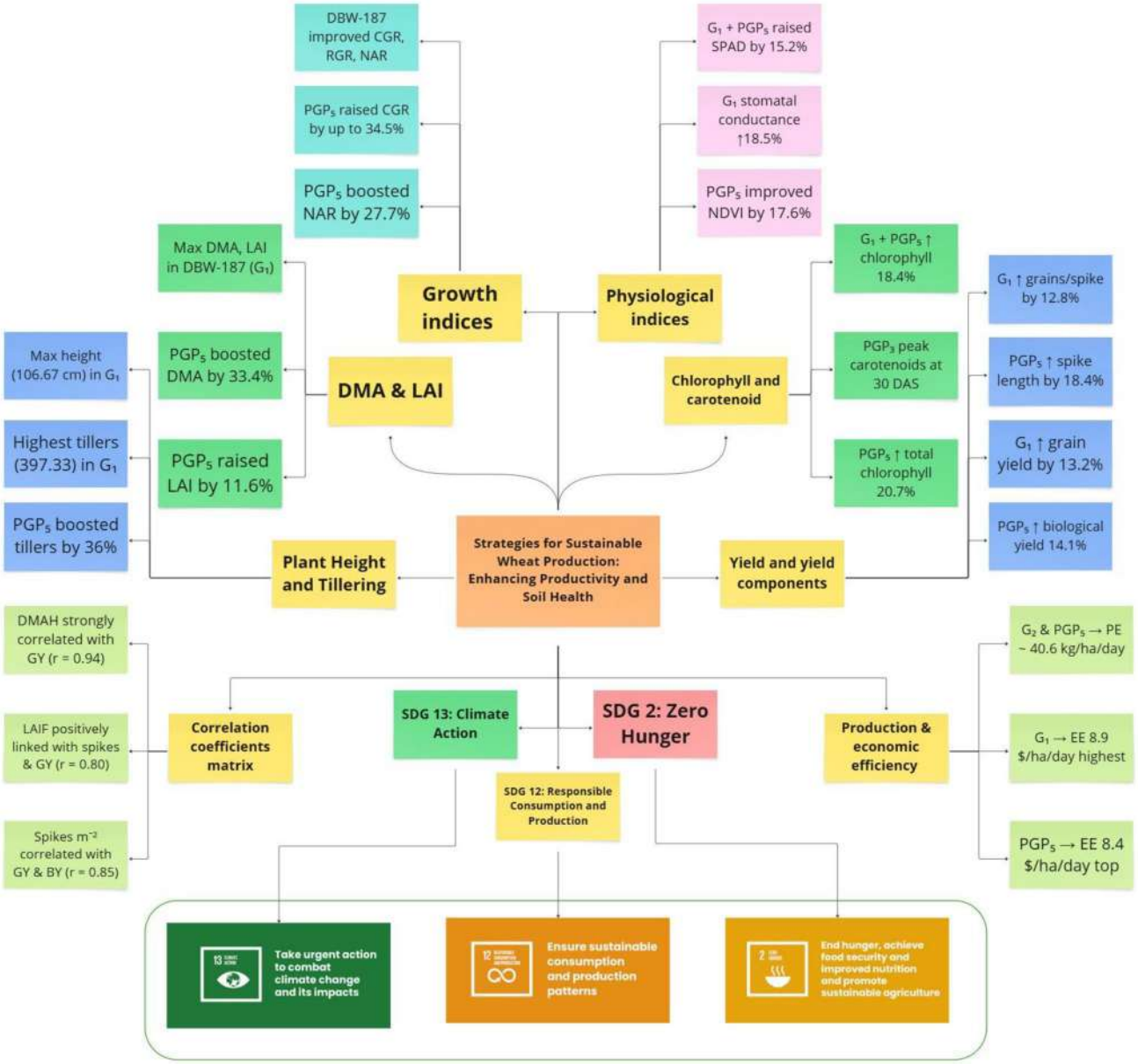


Fig. 9 Strategies for sustainable wheat production and soil health improvement in semi-arid ecologies of India

Author Contributions SKP, VKV: Conceptualization; SKP, SG, SS, GS, SNK: Data curation; DK, MZS, DNS, VSM: Formal analysis; SKP, NS, SKA, VKV: Investigation; SKP, VSM, DK, SK: Methodology; SK, SSR, VSM, MH: Resources; VSM, MH: Software; SS, VSM, MH, MZS: Validation; NS, MH, VSM: Visualization; SKP, MH, VSM, VKV: Writing – original draft; MH, SK, SSR, VSM: Writing – review & editing.

Declarations

Conflict of interest No conflict of interest is declared.

References

Akbar M, Aleem K, Sandhu K, Shamoon F, Fatima T, Ehsan M, Shaukat F (2023) A mini review on insect pests of wheat and their management strategies. Int. J. of Agri. and Biosc 12(2):110–115. https://doi.org/10.47278/journal.ijab/2023.052

Ali O, Ramsubhag A, Jayaraman J (2021) Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production. Plants 10(3):531. https://doi.org/10.3390/plants10030531

Amin E, Pipia L, Belda S, Perich G, Graf LV, Aasen H, van Wittenberghe S, Moreno J, Verrelst J (2024) In-season forecasting of within-field grain yield from Sentinel-2 time series data. Int J Appl Earth Obs Geoinf 126:103636. https://doi.org/10.1016/J.JAG.2023.103636

Asseng S, Ewert F, Rosenzweig C, Jones JW, Hatfield JL, Ruane AC, Wolf J (2013) Uncertainty in simulating wheat yields under climate change. Nat Clim Change 3(9):827–832. https://doi.org/10.1038/nclimate1916

Azameti MK, Tanuja N, Kumar S, Rathinam M, Imoro AM, Singh PK, Gaikwad K, Sreevathsa R, Dalal M, Arora A, Rai V, Padaria JC (2024) Transgenic tobacco plants overexpressing a wheat salt stress root protein (TaSSRP) exhibit enhanced tolerance to heat stress. Mol Biol Rep 51(1):791. https://doi.org/10.1007/s11033-024-09755-4

Bahrani A, Pourreza J (2012) Gibberellic acid and Salicylic acid effects on seed germination and seedlings growth of wheat (*Triticum aestivum* L.) under salt stress condition. World Appl Sci J 18(5):633–641. https://doi.org/10.5829/idosi.wasj.2012.18.05.1372

Bakala HS, Mandahal KS, Sarao LK, Srivastava P (2021) Breeding wheat for biotic stress resistance: achievements, challenges and prospects. IntechOpen. https://doi.org/10.5772/intechopen.97359

Benítez García I, Dueñas Ledezma AK, Martínez Montaño E, Salazar Leyva JA, Carrera E, Ruiz O (2020) Identification and quantification of plant growth regulators and antioxidant compounds in aqueous extracts of *Padina durvillaei* and *Ulva lactuca*. Agronomy 10(6):866. https://doi.org/10.3390/agronomy10060866

Cao J, Qin Z, Cui G et al (2024) Natural variation of STKc_GSK3 kinase TaSG-D1 contributes to heat stress tolerance in Indian Dwarf wheat. Nat Commun 15:2097. https://doi.org/10.1038/s41467-024-46419-0

Chauhan A, Rajput N, Kumar A, Verma JS, Chaudhry AK (2018) Interactive effects of gibberellic acid and salt stress on growth parameters and chlorophyll content in oat cultivars. J Environ Biol 39(5):639–646. https://doi.org/10.22438/jeb/39/5/MRN-615

Chauhan J, Prathibha MD, Singh P, Choyal P, Mishra UN, Saha D, Singhal RK (2023) Plant photosynthesis under abiotic stresses: damages, adaptive, and signaling mechanisms. Plant Stress 10:100296. https://doi.org/10.1016/j.stress.2023.100296

Choudhary M, Meena VS, Yadav RP, Parihar M, Pattanayak A, Panday SC, Mishra PK, Bisht JK, Yadav MR, Nogia M, Samal SK, Ghasal PC, Choudhary J, Choudhary M (2019) Does PGPR and mycorrhizae enhance nutrient use efficiency and efficacy in relation to crop productivity? In: Maheshwari D, Dheeman S (eds) Field crops: sustainable management by PGPR. sustainable development and biodiversity 23. Springer, Cham, pp 71–98. https://doi.org/10.1007/978-3-030-30926-8_3

Chowdhury B, Howlader MHK, Hossain MK, Sikder MC, Hasan MM (2018) Effect of nitrobenzene on growth and yield of Boro rice. Prog Agric 29(4):304–312

Das D, Dwivedi BS, Meena MC, Singh VK, Tiwari KN (2015) Integrated nutrient management for improving soil health and crop productivity. Indian J Fert 11(4):64–83

Deb M, Roy S, Huq SI (2012) Effects of nitrobenzene on growth of tomato plants and accumulation of arsenic. Bangladesh J Sci Res 25(1):43–52

Dhaliwal SS, Sharma V, Shukla AK (2022) Impact of micronutrients in mitigation of abiotic stresses in soils and plants—a progressive step toward crop security and nutritional quality. Adv Agron 173:1–78. https://doi.org/10.1016/bs.agron.2022.02.001

Erenstein O, Jaleta M, Mottaleb KA, Sonder K, Donovan J, Braun HJ (2022) Global trends in wheat production, consumption and trade. Wheat improvement: food security in a changing climate. Springer International Publishing, Cham, pp 47–66. https://doi.org/10.1007/978-3-030-90673-3

Gawdiya S, Kumar D, Shivay YS, Radheshyam, Nayak S, Ahmed B, Mattar MA (2023a) Nitrogen-driven genotypic diversity of wheat (*Triticum aestivum* L.) genotypes. Agronomy 13(10):2447

Gawdiya S, Kumar D, Shivay YS, Kour B, Kumar R, Meena S, Saini Ravi, Choudhary Kamal, Al-Ansari Nadhir, Alataway Abed, Dewidar Ahmed Z., Mattar MA (2023b) Field screening of wheat cultivars for enhanced growth, yield, yield attributes, and nitrogen use efficiencies. Agronomy 13(8):2011

Gomez KA, Gomez AA (1984) Statistical Procedures for Agricultural Research, 2nd ed. John Wiley and Sons, New York, USA, p 680

Hafeez MB, Ramzan Y, Khan S, Ibrar D, Bashir S, Zahra N, Rashid N, Nadeem M, Rahman SU, Shair H, Ahmad J, Hussain M, Irshad S, Al-Hashimi A, Alfagham A, Diao ZH (2021) Application of zinc and iron-based fertilizers improves the growth attributes, productivity, and grain quality of two wheat (*Triticum aestivum*) cultivars. Front Nutr 8:779595

Hanway JJ, Heidel H (1952) Soil analysis methods as used in Iowa state college soil testing laboratory. Iowa Agric 57:1–31

Hussien Ibrahim ME, Zhu X, Zhou G, Adam Ali AY, Ibrahim Elsiddig AM, Farah GA (2019) Response of some wheat varieties to gibberellic acid under saline conditions. Agrosyst Geosci Environ 2(1):1–7. https://doi.org/10.2134/age2019.01.0003

Jat ML, Gupta R, Saharawat YS, Khosla R (2011) Layering precision land leveling and furrow irrigated Raised bed planting: productivity and input use efficiency of irrigated bread wheat in Indo-Gangetic plains. Am J Plant Sci 2(4):578–588. https://doi.org/10.4236/ajps.2011.24069

Jat ML, Bijay-Singh, Gerard B (2014) Nutrient management and use efficiency in wheat systems of South Asia. In D.L. Sparks (Ed.), Advances in Agronomy (Vol. 125, pp. 171–259). Academic Press. https://doi.org/10.1016/B978-0-12-800137-0.00005-4

Jat HS, Kumar V, Datta A, Choudhary M, Singh Y, Kakraliya SK, Poonia T, McDonald AJ, Jat ML, Sharma PC (2020) Designing profitable, resource use efficient and environmentally sound cereal based systems for the Western Indo-Gangetic plains. Sci Rep 10:19267. https://doi.org/10.1038/s41598-020-76035-z

Kakraliya SK, Jat HS, Singh I, Sapkota TB, Singh LK, Sutaliya JM, Sharma PC, Jat RD, Choudhary M, Lopez-Ridaura S, Jat ML (2018) Performance of portfolios of climate smart agriculture practices in a rice-wheat system of Western Indo-Gangetic plains. Agric Water Manage 202:122–133. https://doi.org/10.1016/j.agwat.2018.02.020

Kakraliya SK, Jat HS, Singh I, Gora MK, Kakraliya M, Bijarniya D, Sharma PC, Jat ML (2022) Energy and economic efficiency of climate-smart agriculture practices in a rice–wheat cropping system of India. Sci Rep 12:8731. https://doi.org/10.1038/s41598-022-12686-4

Kasim WA, Elsayed AMH, Shams El-Din NG, Eskander SK (2015) Influence of seaweed extracts on the growth, some metabolic activities and yield of wheat grown under drought stress. Int J Agron Agric Res 7(2):173–189

Khan W, Rayirath UP, Subramanian S, Jithesh MN, Rayorath P, Hodges DM, Prithiviraj B (2009) Seaweed extracts as biostimulants of plant growth and development. J Plant Growth Regul 28:386–399. https://doi.org/10.1007/s00344-009-9103-x

Kohombange S, Gunasekera HKLK, Eeswara JP (2018) Effect of nitrobenzene on yield of bell pepper (*Capsicum annuum* L.) and sweet cucumber (*Cucumis sativus* L.) under green house condition. Int J Res 5(15):926–929

Kulkarni SS, Desai AD, Ranveer RC, Sahoo AK (2012) Development of nutrient rich noodles by supplementation with malted ragi flour. Int Food Res J 19(1):309

Kumar G, Sahoo D (2011) Effect of seaweed liquid extract on growth and yield of *triticum aestivum* var. Pusa gold. J Appl Phycol 23:251–255. https://doi.org/10.1007/s10811-011-9660-9

Kumar R, Mehrotra NK, Nautiyal BD, Kumar P, Singh PK (2009) Effect of copper on growth, yield and concentration of Fe, Mn, Zn and Cu in wheat plants (*Triticum aestivum* L). J Environ Biol 30(4):485–488

Kumar V, Jat HS, Sharma PC, Singh B, Gathala MK, Malik RK, Kamboj BR, Yadav AK, Ladha JK, Raman A, Sharma DK,

McDonald A (2018) Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. Agric Ecosyst Environ 252:132–147. https://doi.org/10.1016/j.agee.2017.10.006

Lal R (2016) Feeding 11 billion on 0.5 billion hectare of area under cereal crops. Food Energy Secur 5(4):239–251. https://doi.org/10.1002/fes3.99

Lamlom SF, Abdelghany AM, Farouk AS, Alwakel ES, Makled KM, Bukhari NA, Shehab AA (2025) Biochemical and yield response of spring wheat to drought stress through gibberellic and abscisic acids. BMC Plant Biol 25(1):5. https://doi.org/10.1186/s12870-024-05879-8

Layek J, Das A, Idapuganti RG, Sarkar D, Ghosh A, Zodape ST, Meena RS (2018) Seaweed extract as organic bio-stimulant improves productivity and quality of rice in eastern Himalayas. J Appl Phycol 30:547–558. https://doi.org/10.1007/s10811-017-1225-0

Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci Soc Am J 42:421–428

Liu B, Asseng S, Müller C et al (2016) Similar estimates of temperature impacts on global wheat yield by three independent methods. Nat Clim Change 6:1130–1136. https://doi.org/10.1038/nclimate3115

Meena SK, Meena VS (2017) Importance of soil microbes in nutrient use efficiency and sustainable food production. In: Meena V, Mishra P, Bisht J, Pattanayak A (eds) Agriculturally Important Microbes for Sustainable Agriculture. Springer, Singapore, pp 1–20. https://doi.org/10.1007/978-981-10-5343-6_1

Meena VS, Meena SK, Verma JP, Meena RS, Ghosh BN (2015a) The needs of nutrient use efficiency for sustainable agriculture. J Clean Prod 102:562–563. https://doi.org/10.1016/j.jclepro.2015.04.044

Meena VS, Verma JP, Meena SK (2015b) Towards the current scenario of nutrient use efficiency in crop species. J Clean Prod 102:556–557. https://doi.org/10.1016/j.jclepro.2015.04.030

Meena RS, Bohra JS, Singh SP, Meena VS, Verma JP, Verma SK, Sihag SK (2016a) Towards the prime response of manure to enhance nutrient use efficiency and soil sustainability: a current need-a book review. J Clean Prod 112:1258–1260. https://doi.org/10.1016/j.jclepro.2015.05.122

Meena SK, Rakshit A, Meena VS (2016b) Effect of seed bio-priming and N doses under varied soil type on nitrogen use efficiency (NUE) of wheat (*Triticum aestivum* L.) under greenhouse conditions. Biocatalysis and Agricultural Biotechnology 6:68–75. https://doi.org/10.1016/j.bcab.2016.02.010

Meena VS, Meena SK, Verma JP, Kumar A, Aeron A, Mishra PK, Bisht JK, Pattanayak A, Naveed M, Dotaniya ML (2017) Plant beneficial rhizospheric microorganism (PBRM) strategies to improve nutrient use efficiency: a review. Ecol Eng 107:8–32. https://doi.org/10.1016/j.ecoleng.2017.06.058

Meena SK, Dwivedi BS, Meena MC, Ghosh A, Datta SP, Singh VK, Mishra RP, Chakraborty D, Singh R, Dey A, Hasanain M, Meena VS (2026a) Unlocking carbon decay kinetics under varying hydrothermal regimes: insights from long-term nutrient supply strategies in the subtropical rice–wheat system. Sustainable Futures 11:101567. https://doi.org/10.1016/j.sftr.2025.101567

Meena VS, Jat RK, Durgude S, Pazhanisamy S, Kumar T, Gautam AK, Kumar S, Reddy IR, Sohane RK, Chhetri KB, Jha RK, Kumar A, Kumar U, Kumar A, Singh RN, Meena SK, Das A, Jha AK, Tripathi DP, Sagar S (2026b) Conservation agriculture for sustainable rice–maize systems in Bihar, India. Field Crops Res 337:110275. https://doi.org/10.1016/j.fcr.2025.110275

Muhammad I, Shalmani A, Ali M, Yang Q-H, Ahmad H, Li FB (2021) Mechanisms regulating the dynamics of photosynthesis under abiotic stresses. Front Plant Sci 11:615942. https://doi.org/10.3389/fpls.2020.615942

Nadeem F, Farooq M (2019) Application of micronutrients in rice-wheat cropping system of South Asia. Rice Sci 26(6):356–371. https://doi.org/10.1016/j.rsci.2019.02.002

Nagar S, Singh VP, Singh N, Dhakar R, Arora A (2022) Effect of endogenous gibberellic acid content on physiological and yield related traits in late sown wheat. Indian J Agric Sci 92(6):700–704. https://doi.org/10.56093/ijas.v92i6.102508

Nayak S, Shivay YS, Prasanna R, Mandi S, Kumar D, Meena SL, Reddy KS (2023) Non-biofortified rice variety responds more to zinc fertilization than biofortified variety in terms of zinc translocation and biofortification. J Soil Sci Plant Nutr 23(3):3313–3328

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939, U.S. Department of Agriculture, Washington, D.C.

Panday SC, Choudhary M, Singh S, Meena VS, Mahanta D, Yadav RP, Pattanayak A, Bisht JK (2018) Increasing farmer's income and water use efficiency as affected by long-term fertilization under rainfed and supplementary irrigation in a soybean–wheat cropping system of Indian mid-Himalaya. Field Crops Res 219:214–221. https://doi.org/10.1016/j.fcr.2018.02.004

Panday SC, Parihar M, Meena RP, Choudhary M, Meena VS, Mondal T, Khati P, Singh AK, Bisht JK, Kant L, Pattanayak A, Singh RD (2024) Long-term fertilization strategies for improving productivity, profitability and water-use efficiency of soybean–wheat cropping systems. J Agric Sci 162:444–457. https://doi.org/10.1017/S0021859624000558

Parađiković N, Teklić T, Zeljković S, Lisjak M, Špoljarević M (2019) Biostimulants research in some horticultural plant species—a review. Food Energy Secur 8(2):e00162. https://doi.org/10.1002/fes3.162

Pazhanisamy S, Singh D, Chandana Devi R, Meena VS, Kumar S, Singh RS, Prasad SS, Devi RS, Prasad JS, Damodar K, Singh A, Sridevi V, Mala S, Kavita, Meena SK (2026) Conservation agriculture for riverine agri-food systems under the climate crisis: enhancing soil health and mitigating erosion. Soil Tillage Res 255:106830. https://doi.org/10.1016/j.still.2025.106830

Piper CS (1950) Soil and plant analysis. Interscience Publishers, Inc., New York, USA, p 368

Prajapati SK, Dayal P, Kumar V, Kumari M (2023) The plant bio-stimulant properties of seaweed extracts: potential to mitigate climate change for sustainable agriculture. Food Sci Rep 4(9):70–75

Prasad R (2005) Rice–wheat cropping systems. Adv Agron 86:255–339. https://doi.org/10.1016/S0065-2113(05)86006-7

Rashid A, Khan MA, Bano A, Ahmed M (2025) Bioformulations of plant growth-promoting rhizobacteria improve wheat productivity under water-deficit conditions. SN Applied Sciences 7(3):125. https://doi.org/10.1007/s42452-025-06605-1

Rathore SS, Chaudhary DR, Boricha GN, Ghosh A, Bhatt BP, Zodape ST, Patolia JS (2009) Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. South Afr J Bot 75(2):351–355. https://doi.org/10.1016/j.sajb.2008.10.009

Redford PJ (1967) Growth analysis formulae-their use and abuse. Crop Sci 7:171–175

Salim BBM, Abdel-Rassoul M (2016) Effect of foliar applications of seaweed extract, potassium nitrate, and potassium silicate on growth, yield, and some biochemical constituents of wheat plants under salt stress. J Biol Chem Environ Sci 11(2):371–391

Sande TJ, Tindwa HJ, Alovisi AMT, Shitindi MJ, Semoka JM (2024) Enhancing sustainable crop production through integrated nutrient management: a focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilizers a systematic review. Front. Agron. 6:1422876. https://doi.org/10.3389/fagro.2024.1422876

Sapkota TB, Singh LK, Yadav AK, Khatri-Chhetri A, Jat HS, Sharma PC, Jat ML, Stirling CM (2020) Identifying optimum rates of fertilizer nitrogen application to maximize economic return and minimize nitrous oxide emission from rice–wheat systems in the Indo-Gangetic plains of India. Arch Agron Soil Sci 66(14):2039–2054. https://doi.org/10.1080/03650340.2019.1708332

Sarwar M, Anjum SA, Hussain M, Shahzad B, Ahmed S (2024) Early vigor wheat genotypes suppress weeds and enhance yield under reduced herbicide inputs. Agron 15(1):103. https://doi.org/10.3390/agronomy1501010

Shaddad MAK, Abd El-Samad HM, Mostafa D (2013) Role of gibberellic acid (GA3) in improving salt stress tolerance of two wheat cultivars. Int J Plant Physiol Biochem 5(4):50–57

Sharma S, Singh P, Dhaliwal SS, Kaur G, Sodhi GPS (2023) Changes in micro-nutrients and their fractions in relation to soil quality indices under rice-wheat, cotton-wheat, and agroforestry in North-Western India. J Soil Sci Plant Nutr 23(4):6357–6376. https://doi.org/10.1007/s42729-023-01490-2

Singh Y, Sidhu HS (2014) Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic plains of India. Proc Indian Natl Sci Acad 80(1):95–114. https://doi.org/10.16943/ptinsa/2014/v80i1/55089

Singh SK, Tomar BS, Anand A, Kumari S, Prakash K (2018) Effect of growth regulators on growth, seed yield and quality attributes in garden pea (*Pisum sativum* var Hortense) cv. Pusa Pragati. Indian J Agric Sci 88(11):1730–1734

Singh M, Kumar P, Kumar V, Solanki IS, McDonald AJ, Kumar A, Poonia SP, Kumar V, Ajay A, Kumar A, Singh DK, Singh S, Malik RK (2020) Intercomparison of crop establishment methods for improving yield and profitability in the rice-wheat system of Eastern India. Field Crops Res 250:107776. https://doi.org/10.1016/j.fcr.2020.107776

Sobolewska M, Wenda-Piesik A, Jaroszewska A, Stankowski S (2020) Effect of habitat and foliar fertilization with K, Zn and Mn on winter wheat grain and baking qualities. Agron 10(2):276

Subbiah BV, Asija GL (1956) A rapid procedure for the estimation of available nitrogen in soils. Curr Sci 25:259–260

Swain SM, Singh DP (2005) Tall tales from sly dwarves: novel functions of gibberellins in plant development. Trends Plant Sci 10(3):123–129

Szczepanek M, Wszelaczyńska E, Poberežny J (2018) Effect of seaweed biostimulant application in spring wheat. AgroLife Sci J 7(1). http://agrolifejournal.usamv.ro/index.php/agrolife/article/view/221

Udgata J, Barik M, Phonglosa A, Joshi SK, Mishra PJ, Rahman FH, Garnayak LM, Parida D (2020) Assessment of balance nutrition (N, P, K, Zn and B) and green manuring on yield, nutrient uptake, economics and soil fertility of rainfed rice (*Oryza sativa* L.) in drought prone areas of Odisha. Curr J Appl Sci Tech 39(27):10–19. https://doi.org/10.9734/cjast/2020/v39i2730915

Ulukan H (2024) Climate Change and Wheat (Triticum spp.). Advances in Wheat Breeding: Towards Climate Resilience and Nutrient Security. Springer Nature Singapore, Singapore, pp 495–524. https://doi.org/10.1007/978-981-99-9478-6_11

USDA (2024) United States department of Agriculture, foreign agricultural Service/USDA. Circular series WAP 02–25 February 2025. World Agricultural Production. https://apps.fas.usda.gov/psdonline/circulars/production.pdf

Vernon LP, Allison JCS (1963) A method for the determination of chlorophylls and carotenoids using spectrophotometry. Anal Chem 35:214–220

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38

Wang W, Sun N, Bai B, Wu H, Cheng Y, Geng H, Song J, Zhou J, Pang Z, Qian S, Zeng W (2024) Prediction of wheat SPAD using integrated multispectral and support vector machines. Front Plant Sci 15:1405068. https://doi.org/10.3389/fpls.2024.1405068

Wankhade RS, Kubde KJ, Sunil K, Deshmukh MR (2020) Effect of bioregulators on growth and yield of chickpea (*Cicer arietinum* L). J Pharmacogn Phytochem 9(4):358–361

Watson DJ (1958) The dependence of net assimilation rate on leaf area index. Ann Bot 22:37–54

Williams CH, Steinbergs A (1959) Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Aust J Agric Res 10:340–352

Xue Y, Yue S, Zhang W, Liu D, Cui Z, Chen X, Ye Y, Zou C (2014) Zinc, iron, manganese and copper uptake requirement in response to nitrogen supply and the increased grain yield of summer maize. PLoS One 9(4):e93895

Yao Y, Wang X, Chen B, Zhang M, Ma J (2020) Seaweed extract improved yields, leaf photosynthesis, ripening time, and net returns of tomato (*Solanum lycopersicum* Mill). ACS Omega 5(8):4242–4249. https://doi.org/10.1021/acsomega.9b04155

Yengoh GT, Dent D, Olsson L, Tengberg AE, Tucker III CJ (2015) Use of the Normalized Difference Vegetation Index (NDVI) to assess Land degradation at multiple scales: current status, future trends, and practical considerations. Springer. https://doi.org/10.1007/978-3-319-24112-8

Zeidan MS, Mohamed MF, Hamouda HA (2010) Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. World J Agric Sci 6(6):696–699

Zhang Q, Men X, Hui C, Ge F, Ouyang F (2022) Wheat yield losses from pests and pathogens in China. Agric Ecosyst Environ 326:107821. https://doi.org/10.1016/j.agee.2021.107821

Zhang Z, Ma S, Yin M, Zhao C, Zhao X, Yu Y, Wang H, Li X, Si Y, Niu J, Xie J, Wang L, Zhang Y, Zheng Q, Zheng S, Jiang N, Liu X, He F (2025) Population-scale gene expression analysis reveals the contribution of expression diversity to 1 the modern wheat improvement. https://doi.org/10.1101/2025.02.18.638840

Zhiipao RR, Pooniya V, Kumar D, Biswakarma N, Shivay YS, Dass A, Kumar Bainsla N, Lakhena KK, Pandey RK, Burman A, Bhatia A, Jat RD, Govindasamy P, Swarnalakshmi K, Das K, Choudhary RL, Babu S (2023) Above and below-ground growth, accumulated dry matter and nitrogen remobilization of wheat (*Triticum aestivum*) genotypes grown in PVC tubes under well-and deficit-watered conditions. Front Plant Sci 14:1087343.a

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Anthology The Research

Indian Knowledge Tradition and Mahatma Gandhi s Work

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Abstract

This paper examines the deep and multifaceted relationship between the Indian Knowledge Tradition (IKT) a broad, pluralistic intellectual and ethical heritage encompassing the Vedic corpus, Upanishadic metaphysics, the epics (Mahabharata and Ramayaṇa), classical darsanas (philosophical systems), and diverse folk and devotional strands — and the life, thought, and practice of Mohandas Karamchand Gandhi (1869–1948). It argues that Gandhi's political praxis and moral pedagogy cannot be fully understood apart from his rootedness in a variety of Indian intellectual resources, reinterpreted in light of modern exigencies and global ethical concerns. After delineating the principal features of IKT relevant to social and political life (notions of dharma, ahimsa, satya, loka-samgraha, tapas, and seva), the paper traces how Gandhi drew upon, reworked, and at times innovated within those resources to formulate Satyagraha, constructive programs, and an ethic of trusteeship. Attention is given to Gandhi's selective appropriation of epic narratives (especially the Bhagavad Gita and episodes from the Ramayaṇa and Mahabharata), his use of indigenous institutions and crafts (khadi and village panchayats) as carriers of knowledge and moral formation, and his dialogic engagement with bhakti and jnana traditions. The study locates Gandhi's epistemic stance — his insistence on lived verification (experiential knowledge), the unity of knowledge and action, and the moral primacy of the self-transformation of the actor — within broader strands of Indian epistemology while noting tensions with classical scholasticism and Western liberalism. Finally, the paper assesses Gandhi's legacy for contemporary debates on decolonizing knowledge, sustainable living, and nonviolent politics. The analysis concludes that Gandhi stands as a living synthesis: neither uncritical traditionalist nor wholesale modernizer, but a thinker who sought to translate the core insights of IKT into an ethical politics capable of addressing the moral crises of his time and ours.

Keywords

Indian Knowledge Tradition; Mahatma Gandhi; Satyagraha; Ahimsa; Dharma; Bhagavad Gita; Ramayana, Mahabharata, Decolonization of Knowledge; Constructive Program.

Introduction

The Indian Knowledge Tradition (IKT) is not a monolithic school but a tapestry of discourses — philosophical, religious, ethical, juridical, aesthetic, and technical — that developed over millennia across South Asia. It encompasses ways of knowing (pramaṇas and sastric reasoning), pedagogies of character (sadhana and tapas), narrative reservoirs (epics and puraṇas), and institutional forms (gurukula, matha, village assemblies). Mahatma Gandhi emerged from this milieu and became one of the twentieth century's most widely read interpreters of Indian moral resources. Yet his use of IKT was selective, creative, and adapted to the political task of national liberation and social renewal. Understanding Gandhi's work thus requires a careful reading of how he drew on and transformed IKT concepts — not merely as cultural stock but as living tools for moral and political action.

This paper proceeds in four parts. The first outlines the salient elements of IKT relevant to social ethics and political practice. The second traces Gandhi's engagement with those elements in the formulation of his ideas and methods. The third examines case studies where IKT-inflected practice shaped politics (for example, nonviolent resistance, khadi, constructive program). The fourth assesses the broader implications of Gandhi's IKT-rooted approach for contemporary intellectual and political challenges, including the decolonization of knowledge, ecological sustainability, and nonviolent politics.

Objective of study

1. To examine the foundational principles of the Indian Knowledge Tradition (IKT), including its philosophical, ethical, and spiritual components.
2. To explore the ways in which Mahatma Gandhi's life, thought, and work were shaped by the Indian Knowledge Tradition.
3. To analyze Gandhi's reinterpretation of classical Indian texts such as the Bhagavad Gita, Upanishads, and Jain/Buddhist teachings.
4. To investigate Gandhi's application of Indian philosophical values—such as satya, ahimsa, brahmacharya, and aparigraha—in socio-political movements.

5. To study how Gandhi transformed traditional concepts into practical programmes like Satyagraha, Sarvodaya, and constructive work.
6. To assess the relevance of Gandhian thought in contemporary issues like environmental ethics, sustainability, peace studies, and global justice.
7. To understand Gandhi's critique of Western modernity and his emphasis on indigenous ways of knowing and living.
8. To evaluate Gandhi's contribution to preserving, revitalizing, and internationalizing Indian Knowledge Tradition.
9. To explore the interconnection of ethics, spirituality, and political activism within Gandhi's framework.
10. To discuss the relevance of Indian Knowledge Tradition in shaping alternative models of education, economy, and social development.
11. To examine how Gandhi's ideas influenced later thinkers, activists, and global movements for peace and civil rights.

Review of Literature

Indian Knowledge Tradition and Mahatma Gandhi's Work. Indian Knowledge Tradition (IKT) signifies a civilizational continuum of philosophical inquiry, ethical living, socio-spiritual practices, and indigenous epistemologies cultivated over millennia. Rooted in the Vedas, Upanishads, classical philosophies, oral traditions, and community knowledge systems, IKT emphasizes harmony with nature, holistic well-being, discipline, and moral responsibility. Mahatma Gandhi's work intersects deeply with these traditions, as scholars note his philosophy of ahimsa, swaraj, and sarvodaya reflects ancient Indian ethical thought.

Indian philosophical foundations originate in texts such as the Upanishads and Bhagavad Gita. Radhakrishnan argues that Indian tradition centers on truth and moral order. Vatsyayan emphasizes the interdisciplinary nature of Indian knowledge, integrating spiritual and practical wisdom. Chattopadhyaya stresses the balance of jnana, karma, and dharma. Scholars note Gandhi's interpretation of ahimsa and satyagraha draws heavily on classical ethics. Parekh states that Gandhi transformed ancient values into socio-political instruments. Parel explains that Gandhi's reading of the Gita reimagined nishkama karma as selfless action. Gandhi's exposure to Jainism shaped his non-violence and pluralism, as Jordens notes. His Nai Talim educational philosophy aligns with ancient holistic learning models.

Gandhi's swaraj and swadeshi, scholars argue, reflect traditional ideas of autonomy and dharma. The concept of sarvodaya echoes classical notions of loka-sangraha. His ecological critiques reflect Indian traditions of restrained living, as Guha observes. Gandhi's social reform agenda resonates with Bhakti and Buddhist egalitarian traditions.Contemporary debates explore Gandhi's reinterpretation of tradition. Some view it as creative adaptation; others critique selective appropriation. Environmental scholars see Gandhi as a precursor to sustainability rooted in traditional ecological ethics.

Understanding Gandhi, the literature suggests, requires engaging with India's vast knowledge traditions, whose ethical, spiritual, and social philosophies shaped his thought and activism.

Main Text

Deeper Dimensions of the Indian Knowledge Tradition

The Indian Knowledge Tradition is not only a reservoir of ideas but also a dynamic interplay of competing and complementary schools of thought. Gandhi's intellectual appropriation can be better understood when we look more closely at the six classical darsanas.

Nyaya and Vaiseṣika: Nyaya emphasizes logic, reasoning, and epistemology, while Vaiseṣika develops a naturalistic metaphysics of categories (padarthas). Gandhi may not have directly cited these schools, yet his insistence on rational dialogue, debate with critics, and evidence-based moral reasoning echoes Nyaya's spirit. His ecological awareness and sensitivity to the interconnectedness of matter, beings, and spirit reflects a Vaiseṣika-like worldview.

Saṃkhya and Yoga: Saṃkhya provides a dualistic framework of puruṣa (consciousness) and prakṛti (matter), while Yoga, systematized by Patanjali, emphasizes discipline, restraint, meditation, and ethical precepts (yamas and niyamas). Gandhi's daily regimen of prayer, dietary restraint, fasting, and meditation drew from yogic traditions, not as esotericism but as moral preparation for political struggle. His life demonstrates the practical use of yoga for cultivating inner strength essential for nonviolent activism.

Mimaṃsa and Vedanta: Mimaṃsa stresses ritual performance and dharma as duty, whereas Vedanta emphasizes non-duality and the realization of Brahman as ultimate truth. Gandhi fused aspects of both: the Mimaṃsa-like stress on moral obligation (to act, to resist injustice, to serve) and Vedanta's emphasis on unity of life. Gandhi repeatedly affirmed that "Truth is God" — an inversion of Vedantic formulations that still retained the core metaphysical insight.

By drawing from these diverse schools, Gandhi exemplifies how IKT provided a multi-layered framework adaptable to new contexts. His genius lay in refusing to be bound by any single darsana, instead using them as flexible instruments to construct a holistic ethic of action.

The Ramayana and Mahabharata in Gandhian Moral Vision

The epics played an important role in Gandhi's ethical imagination. The **Ramayaṇa**'s central theme of dharma resonated with him deeply. Gandhi often cited Rama asan embodiment of truth, not merely as a divine king but as an exemplar of moral steadfastness in adversity. Sita, too, was highlighted as a figure of strength, sacrifice, and purity of intention. Gandhi interpreted their lives allegorically: dharma was not ritual or power but the courage to uphold truth and righteousness despite suffering.

The **Mahabharata**, especially the **Bhagavad Gita**, was Gandhi's "spiritual dictionary." He treated the Kurukṣetra war not as literal encouragement to violence but as a metaphor for the inner battle between good and evil within the human heart. Arjuna's paralysis mirrored Gandhi's own dilemmas in confronting colonial power. Krishna's teaching of detached action became Gandhi's cornerstone: act without attachment to success or failure, but guided by truth and ahimsa.

Interestingly, Gandhi also invoked **Ahimsa from the Mahabharata**, despite its martial setting. He reminded his followers that even the epic, filled with bloodshed, contains passages condemning violence and celebrating compassion. Thus, Gandhi used the epics not as texts frozen in antiquity but as living sources for moral reinterpretation.

Gandhi's Constructive Program in Greater Depth

While Satyagraha is often highlighted as Gandhi's main contribution, his **Constructive Program** reveals his deeper connection to IKT. Gandhi believed true swaraj (self-rule) was not merely political independence but moral and social regeneration. The constructive program included:

Khadi and Village Industries: Gandhi made spinning a moral duty, not only for economic self-reliance but also for cultivating dignity of labor. In IKT terms, work (karma) is both duty and discipline; the spinning wheel thus became a locus of spiritual practice.

Sanitation and Hygiene: Drawing on IKT's emphasis on purity (sauca), Gandhi made cleanliness a moral obligation. He himself cleaned toilets in ashrams, breaking caste taboos and demonstrating that no task is impure if done with humility and service.

Education (Nai Talim): Gandhi's model of basic education embodied IKT pedagogy — learning through practice, integration of craft, literacy, and moral training. Unlike colonial education, which alienated students from their communities, Nai Talim sought to root knowledge in lived experience.

Communal Harmony: Gandhi saw inter-religious unity as essential to swaraj. Drawing on IKT's pluralism, he emphasized that all religions are paths to the same truth. His recitation of verses from the Qur'an, Gita, and Bible in prayer meetings symbolized this inclusivity.

The constructive program reflects Gandhi's belief that liberation is incomplete without a transformation of daily life. It demonstrates how IKT was woven into social structures, crafts, and moral disciplines.

Gandhi, IKT, and Global Impact

Gandhi's synthesis of IKT principles did not remain confined to India. His method inspired global leaders and movements.

Martin Luther King Jr. explicitly acknowledged Gandhi's influence on the American Civil Rights Movement. King saw in Gandhi's Satyagraha an application of Christian love in social struggle, yet the roots of nonviolent resistance lay in Gandhi's reworking of ahimsa and satya.

Nelson Mandela and the South African anti-apartheid movement drew on Gandhian tactics as well. Gandhi's early experiments in South Africa had already demonstrated the effectiveness of nonviolent resistance against racial injustice. Mandela later reflected that while armed struggle eventually became part of their movement, Gandhi's nonviolence remained a moral touchstone.

Decolonial Thought: In contemporary postcolonial studies, Gandhi is recognized as a thinker who challenged the epistemic dominance of Western categories. His retrieval of IKT demonstrated that indigenous knowledge systems could inform modern politics, economics, and ethics without mimicking the West. This has become crucial in present debates about the decolonization of curricula and sustainable development

Core Features of the Indian Knowledge Tradition Relevant to Gandhi

1. Dharma and Moral Order

Dharma in the Indian tradition is a complex category: normative duty, moral order, appropriate conduct, and the sustaining principle of social and cosmic order. Unlike a fixed legal code, dharma operates contextually — it is rooted in position, circumstance, and the larger telos of one's life. This fluidity allowed Gandhi to emphasize moral responsibility that adapts to context rather than rigidly invoking customary law. For Gandhi, dharma became the moral grammar of action: a principle that obliges the actor toward truth, non-harm, and service.

2. Ahimsa (Nonviolence)

Ahimsa is more than the abstention from physical violence; it denotes an active ethic of non-harming that encompasses thought, word, and deed. Ahimsa has roots in Jain, Buddhist, and certain Hindu strands, but across traditions it is linked with compassion and the recognition of intrinsic worth in all beings. Importantly, traditional formulations of ahimsa are embedded in disciplining practices and communal norms — not merely

abstract doctrines — which made the concept available for Gandhi as a practical stance guiding political struggle.

3. Satya (Truth) and Sadhana (Spiritual Discipline)

Satya in classical Indian contexts refers to truth as ontological and ethical — the correspondence between reality and knowledge and the moral commitment to veracity. Coupled with sadhana (disciplined practice), satya requires an ongoing verification through the life of the knower. Gandhi emphasized truth as experiential: the truth one discovers by living and testing one's convictions in the world.

4. Epics and Moral Exemplars

The epics — the Ramayaṇa and Mahabharata (including the Bhagavad Gita) — function as vast reservoirs of ethical dilemmas, models of action, and narrative instruction. Rather than read as literal history, these texts offer paradigms for moral choice. The Gita's discourse on duty, detachment, and right action provided Gandhi with a language to reconcile moral commitment with active engagement.

5. Knowledge as Practice: Jnana, Karma, and Bhakti

Classical Indian thought identifies multiple paths to realization: jnana (knowledge/wisdom), karma (action), and bhakti (devotion). IKT emphasizes that ultimate understanding is not merely speculative but emerges in the lived unity of action, devotion, and insight. This integration resonates with Gandhi's insistence that theory without practice is hollow and that inner transformation is necessary for genuine social reform.

6. Communities of Learning and Local Knowledge

Traditional forms of pedagogy — the gurukula, village assemblies, craft guilds — embed learning within social life. Knowledge is transmitted through apprenticeship, ritual, and shared labor. This communal aspect of knowledge underpinned Gandhi's esteem for village institutions, crafts, and forms of indigenous education.

Gandhi's Intellectual Reception and Reworking of IKT

1. Early Formation and Intellectual Milieu

Gandhi's formation was eclectic: rooted in Gujarati bhakti culture, shaped by English education, and deepened through encounters with Bible teachings, Tolstoy, Ruskin, and experiences in South Africa. Crucially, he never abandoned Indian moral vocabularies. Instead, he reinterpreted them through a moral-practical hermeneutic: what do the ancient categories mean when the moral agent confronts colonial injustice, modern machinery, and mass politics?

2. Satyagraha as IKT-Inspired Practice

Satyagraha a central innovation of Gandhi is commonly translated as "truth-force" or "soul-force." It synthesizes satya and agraha (firmness), yet it is far more than a rhetorical synthesis: it is a method of nonviolent resistance based on moral persuasion, self-suffering, and the expectation of the opponent's conscience being touched. The elements of ahimsa and satya are explicit; so too is the emphasis on inner discipline (tapas) that renders the satyagrahi credible. The Indian lineage is evident in the stress on moral exemplarity and the sacrificial dynamics of tapas.

3. Reinterpretation of the Bhagavad Gītā

Gandhi's appropriation of the Gita is marked by a moral reading rather than a metaphysical one. He rejected deterministic readings that might justify violence as duty. Instead, Gandhi stressed the Gita's message of disinterested action (nishkama karma) and insisted that action must be guided by ahimsa and satya. The battlefield image becomes an ethical arena where inner conquest matters as much as outer victory.

4. Bhakti, Humility, and the Moral Imagination

Gandhi's practice included devotional elements: fasting, singing bhajans, and ritual practices refashioned into moral exercises. Bhakti traditions' emphasis on surrender and love became a resource for cultivating humility and openness- psychological conditions essential for nonviolent persuasion.

5. Constructive Program and Village Swaraj

Gandhi's constructive program-village self-sufficiency, khadi, sanitation, basic education, and communal harmony-reflects the IKT insistence on situated knowledge and embodied practices. Knowledge is carried by craft, ritual, and local institutions; thus, social change requires rebuilding centers of life and learning rather than merely seizing state power.

Case Studies: IKT in Gandhi's Political Practice

1. Nonviolent Resistance in South Africa and India

Gandhi's campaigns — passive resistance in South Africa and mass civil disobedience in India -illustrate his method of turning moral conviction into political leverage. The satyagrahi's willingness to accept suffering aimed to reveal the moral injury of oppressive policies. The strategy presumes a shared moral grammar (conscience, fair play) and appeals to the opponent's humanity- an appeal rooted in IKT's universalist ethical claims about the unity of life and the sacredness of the person.

2. Khadi and Economic Ethics

The khadi movement sought to reorient economic life from commodity-driven industrialism to village-based production. This program drew on IKT's valuation of local crafts as repositories of knowledge and as means of moral formation-work as sadhana. Khadi also represented an ethical critique of industrial modernity: a preference for

human-scale production, ecological prudence, and dignity of labor.

3. Education: Nai Talim (Basic Education)

Gandhi proposed Nai Talim, an education integrating handicraft and literacy, to form self-reliant persons. The approach echoes IKT pedagogies that value embodied skill, oral transmission, and moral formation through daily tasks. Education was not primarily vocational but aimed at shaping character, inculcating communal responsibility, and fostering critical self-reliance.

4. Fasting and Moral Persuasion

Gandhi's strategic fasting demonstrates an IKT-inflected method: ascetic practices as forms of ethical witness. In many Indian traditions, fasting is a disciplining technique to purify will and to invoke communal reflection. Gandhi deployed it as moral pedagogy-to dramatize injustice, to humble the oppressor, and to awaken consciences.

5. Interreligious Dialogue and Pluralism

IKT's pluralistic character multiple paths to truth recognized across schools fostered Gandhi's approach to religious pluralism. He treated religions as distinct yet complementary search-lights toward truth, a stance that enabled him to craft inclusive campaigns and to seek Hindu-Muslim unity despite communal tensions.

Philosophical and Methodological Stakes

1. Epistemology: Experiential Verification and Moral Knowledge

Gandhi insisted that intellectual assent is insufficient: truth must be tested in experience. This echoes Indian epistemic emphases on pratyakṣa (perception) and anubhava (experience) as sources of knowledge. Gandhi's methodology valued reflective praxis actors learn through doing, through the moral consequences their acts produce, and through disciplined self-observation.

2. Ethics: Agency, Responsibility, and Non-Hierarchical Leadership

Gandhi's ethics decentralizes authority: moral agency resides in the individual's capacity for self-transformation and service. The leader's legitimacy derives from ascetic discipline and moral integrity rather than bureaucratic power. This aligns with IKT's valorization of the teacher's character and of exemplarity as pedagogical force.

3. Politics: Means and Ends

A distinctive Gandhi contribution is the inseparability of means and ends. Drawing from IKT's moral holism, Gandhi argued that unjust means cannot produce just ends; therefore political action must itself be a moral instrument. This critique stands in tension with certain modern realpolitik tendencies and challenges utilitarian justifications for violence.

4. Tensions and Critiques

Gandhi's use of IKT was not without tension. Critics argue he romanticized village life, undervalued industrial modernization's potential benefits, or was ambiguous on caste issues earlier in his career. Moreover, some classical IKT strands (e.g., caste ritualism) conflicted with Gandhi's egalitarian impulses; he selectively criticized and sought reform within tradition. The dialectic between preservation and critique lies at the heart of Gandhi's project.

Legacy: Gandhi, IKT, and Contemporary Debates

1. Decolonizing Knowledge

In contemporary debates about decolonizing knowledge, Gandhi's method offers a template: recover indigenous epistemic resources, but subject them to moral-critical reworking. IKT, in Gandhi's hands, becomes not a nostalgic repository but a dynamic toolkit for addressing modernity's ethical deficits.

2. Sustainable Living and Ecological Ethics

Gandhi's preference for small-scale production and moderation resonates with current sustainability movements. IKT's emphasis on harmony with nature and limits provides philosophical underpinnings for ecological ethics that prioritize sufficiency over limitless growth.

3. Nonviolent Resistance in Global Contexts

Gandhi's synthesis of spiritual discipline and political strategy has inspired movements worldwide. The IKT-rooted logic that transforming the self is prerequisite for transforming structures challenges activists to pair external change with internal formation.

4. Education for Character and Skill

The Nai Talim model reappears in contemporary proposals for craft-centered, community-oriented education that fosters employability, civic responsibility, and ethical sensibility. IKT's pedagogical forms emphasize mentoring, contextual learning, and integration of work and values.

Conclusion

Mahatma Gandhi's intellectual and political career cannot be disentangled from the Indian Knowledge Tradition. He was both an inheritor and a creator: drawing on dharma, ahimsa, satya, and the epics while transforming these sources into practical strategies for nonviolent struggle, social reconstruction, and moral formation. Gandhi's originality lay in insisting upon the unity of knowledge and action and in treating moral self-transformation as a political instrument. The IKT provided him with vocabularies, symbols, institutions, and practices that he retooled to face the modern world's exig Mahatma Gandhi's engagement with the Indian Knowledge Tradition was not a simple

return to the past, but a profound act of translation. By reinterpreting dharma, ahimsa, satya, and the epic traditions, he forged an ethic that spoke both to villagers spinning khadi and to global leaders confronting racism and imperialism. Gandhi transformed IKT from a cultural inheritance into a living praxis of politics and spirituality.

In our time of ecological crisis, violent conflicts, and epistemic domination by Western models, Gandhi's method remains relevant. His call for simplicity resonates with sustainability movements; his emphasis on nonviolence addresses the escalating cycles of global conflict; and his insistence that knowledge must be embodied in action challenges academic and political institutions alike. Thus, Gandhi is neither an antiquarian traditionalist nor a utopian dreamer. He is, instead, a thinker who demonstrates how rooted traditions can be critically reimagined for contemporary liberation. His life shows that the Indian Knowledge Tradition is not merely a museum of the past but a living reservoir of wisdom for global futures.Gandhi's legacy suggests a constructive path for contemporary societies: engage indigenous knowledge critically, retrieve ethical resources suited to present challenges, and design political means that reflect the ends desired. Whether one accepts all of Gandhi's prescriptions, his method a dialogic, experiential, ethically rigorous engagement between tradition and modernity remains instructive. It invites scholars and practitioners to consider knowledge not simply as information but as embodied practice that shapes persons, communities, and the common good.

References

1. *Bhagavad Gita. Translations and commentaries; classical Hindu scripture embedded in the Mahabharata.*
2. *Mahabharata. Epic narrative attributed to Vyasa*
3. *Ramayaṇa. Epic narrative attributed to Valmiki.*
4. *Upaniṣads. Classical Vedantic texts on philosophy and knowledge*
5. *Gandhi, Mohandas K. Hind Swaraj (1909)*
6. *Gandhi, Mohandas K. An Autobiography: The Story of My Experiments with Truth.*
7. *Gandhi, Mohandas K. Satyagraha in South Africa*
8. *Gandhi, Mohandas K. Constructive Program: Its Meaning and Place.*

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Effect of precision farming techniques on resource use efficiency and crop performance

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Abstract
This essay examines how precision farming techniques reshape agricultural decision-making to improve resource use efficiency and crop performance. It synthesizes evidence on site-specific management tools—such as variable-rate application, remote sensing, and GPS-guided operations—that match inputs to spatial and temporal crop needs, thereby lowering input waste and stabilizing yields. The discussion evaluates water, nutrient, and energy use outcomes, highlighting reductions in application rates per unit output, alongside improvements in yield stability and quality traits linked to timely interventions. It further assesses agronomic mechanisms, including feedback-driven adjustments and within-field heterogeneity management, that translate measurement into actionable control, while noting operational constraints related to data quality and system integration. Finally, the essay reviews economic and environmental consequences of these practices and outlines emerging innovations, setting a research agenda that connects technical performance with adoption contexts, risk management, and scalable decision support for diverse production systems.

Keywords: Precision farming, resource use efficiency, crop performance, site-specific management and smart agriculture

Introduction

Against the backdrop of rising input costs and variable climate conditions, precision farming refers to a management approach that tailors agronomic decisions to spatial and temporal variability within fields. Using sensing, geolocation, and data-driven control, producers align water, nutrients, and crop protection with measured crop demand, thereby reducing unnecessary applications while stabilizing physiological development. This approach has gained momentum as digital tools have matured and as production systems face tightening environmental regulations and heightened market pressures for consistent quality. In this essay, the analysis concentrates on how site-specific interventions alter resource use efficiency, measured as output per unit of water, nutrient, and energy applied, and how these interventions affect yield levels, uniformity, and quality attributes. The discussion follows a mechanistic thread from measurement to decision to actuation, then evaluates agronomic outcomes alongside operational constraints, before turning to economic trade-offs, environmental outcomes, and emergent technological directions relevant to broader adoption.

Overview of Precision Farming Techniques

Meanwhile, precision farming integrates three interlocking components: geolocation, sensing, and analytics-driven control. GPS and GNSS guidance support auto-steering, section control, and variable-rate capabilities that align machinery paths and input placement with mapped field variability, while RTK corrections enable centimeter-level repeatability for controlled traffic and site-specific trials. On the sensing side, proximal soil probes, canopy reflectance sensors, machine-mounted yield monitors, and UAV or satellite imagery provide continuous measurements of moisture, nutrient status, and biomass, which are synchronized with spatial coordinates to build temporally resolved management zones. Data analytics then convert these measurements into prescriptions through models and decision rules that run on farm management platforms, with AI methods increasingly applied to classify stress, predict growth stages, and optimize input timing from IoT data streams (Raj *et al*., 2021) [10]. Finally, actuation occurs through variable-rate seeders, fertilizer applicators, and irrigation systems, translating prescriptions into precisely metered field operations linked to feedback loops (Raj *et al*., 2021) [10].

Additionally, the historical trajectory of precision agriculture traces a shift from early yield monitors and differential GPS in the 1990s to integrated sensing–analytics–actuation systems that now operate across seasons. Initial adoption centered on mapping spatial variability to guide fertilizer placement, but subsequent advances in GNSS accuracy and section control reduced overlap, improved pass-to-pass repeatability, and enabled on-farm experimentation that refined prescriptions. The 2010s introduced widespread remote sensing and connected machinery, while recent developments in machine vision, AI-driven classification, and IoT networks moved decision-making from periodic mapping toward continual, in-season adjustment (Zaman, 2023) [15]. Motivations for adoption have mirrored these phases: producers sought input savings and labor efficiency first, then pursued yield stability, quality consistency, and risk reduction under price volatility and climate variability, with regulatory pressure on nutrient losses reinforcing these incentives. Policy interest and maturing service ecosystems further lowered entry barriers by aligning profitability aims with conservation goals and by standardizing data handling and support pathways (Zaman, 2023) [15].

Furthermore, the central goals of precision farming coalesce around aligning input application with measured crop demand to optimize use, reduce waste, and advance

sustainability across production systems. By calibrating water, nutrients, and crop protection to spatial and temporal variability, managers seek higher output per unit of input while constraining off-target losses that raise costs and degrade surrounding ecosystems (Finger *et al*., 2019) [5]. These goals extend beyond single-season margins: site-specific control aims to stabilize yield formation under variable weather, limit soil and water contamination from residual agrichemicals, and document stewardship outcomes that are increasingly relevant to market and regulatory requirements (Finger *et al*., 2019) [5]. In operational terms, prescriptions target the minimum effective dose and timing that maintain crop physiological thresholds, thus shrinking variability within fields and enabling repeatable performance across years. As the previous section's toolset indicates, these objectives depend on data quality and feedback-driven actuation, which together convert monitoring into corrective actions that support both profitability and environmental compliance.

Resource Use Efficiency in Agriculture

Consequently, resource use efficiency in agriculture can be defined as the ratio of useful agronomic output—such as marketable yield or quality attributes—to the quantity of a specific input consumed, typically measured for water, nutrients, energy, and land over a given period. This framing links productivity with stewardship because higher output per unit input reduces costs and lowers off-site losses, thereby aligning farm management with regulatory and market pressures described earlier. In practice, efficiency hinges on matching application dose and timing to crop demand so that physiological thresholds are met without surplus, a control problem that precision farming addresses through geolocation, sensing, and variable-rate actuation (Ahmad & Dar, 2020) [1]. The same framework applies to fertilizers, where spatially targeted and temporally tuned applications curtail residual nitrogen while lifting nitrogen-use efficiency at field scale, with documented reductions in residues and marked gains in conversion efficiency supporting the economic and environmental case (Ahmad & Dar, 2020) [1]. Thus, efficiency metrics provide actionable performance indicators that connect data-driven decisions to sustainable food production targets.

However, conventional uniform-rate practices often misalign input supply with within-field variability, causing frequent over-application of water and fertilizers that depresses marginal returns and elevates off-site losses. Fixed irrigation schedules ignore spatial differences in soil texture and water-holding capacity, so some zones receive excess water that leaches nutrients while others remain under-supplied, reducing water-use efficiency and destabilizing canopy function across growth stages. Similarly, blanket fertilizer programs apply doses to the average condition rather than to measured need, creating high-residual areas where nitrate leaching and nitrous oxide emissions rise, alongside low-fertility patches that constrain root uptake and limit yield potential. These inefficiencies persist because traditional scouting and manual record-keeping provide coarse feedback, delaying corrective actions and reinforcing routines that favor operational simplicity over data-informed adjustment, in contrast to sensing and variable-rate methods that target dose and timing to site conditions (Sharma, 2023) [12]. As a result, baseline efficiency metrics under legacy methods frequently lag behind benchmarks achievable with site-specific management (Sharma, 2023) [12].

In contrast, precision farming corrects the misallocation inherent in uniform-rate methods by pairing targeted application with continuous, spatially explicit monitoring. GPS-guided machinery and section control limit overlap while variable-rate applicators meter seed, fertilizer, and irrigation to prescription maps that reflect measured heterogeneity, thereby aligning dose with localized crop demand and preventing surplus in high-residue zones (Vellingiri *et al*., 2024) [14]. Concurrently, proximal sensors and drone imagery provide near-real-time signals on soil moisture, canopy vigor, and microclimate, enabling managers to adjust timing and quantity during critical growth windows rather than after losses occur (Vellingiri *et al*., 2024) [14]. These feedback loops convert detection into immediate control actions—for example, pausing irrigation where soil water is adequate, advancing nitrogen in emerging deficits, or targeting crop protection only to detected hotspots—thus raising output per unit input while curbing leaching and runoff. By integrating guidance, sensing, and actuation, the system reduces operational lag, supports within-season corrections, and establishes traceable efficiency gains at field scale.

For instance, capacitance and tensiometric soil moisture sensors placed at multiple depths feed continuous readings into irrigation controllers, allowing thresholds for refill to be set by crop stage and soil texture so that water is applied only where root zones approach deficit (Mohammed Aarif K. O. *et al*., 2025) [9]. Variable rate irrigation (VRI) systems then translate zone-specific prescriptions into independently actuated sprinkler banks or drip valves, matching application depth and pulse frequency to mapped variability and thereby reducing percolation in coarse-textured areas while preventing stress on heavier soils. Complementing in-ground measurements, UAV-mounted multispectral cameras estimate canopy water status through indices linked to stomatal conductance, which trigger spatial adjustments to irrigation when thermal signatures indicate emerging stress before visible wilting (Mohammed Aarif K. O. *et al*., 2025) [9]. Edge-computing gateways aggregate sensor and weather data, run evapotranspiration models, and update setpoints in near real time, narrowing the gap between detection and actuation during heat events. Additionally, AI-based fusion of soil probes, environmental sensors, and hyperspectral inputs filters noise and refines zone boundaries for subsequent VRI passes (Mohammed Aarif K. O. *et al*., 2025) [9].

Similarly, precision nutrient management systems align fertilizer dose, placement, and timing with mapped soil variability to raise nutrient-use efficiency while curbing residual losses and costs. GIS layers from soil sampling, yield maps, and terrain attributes are combined to delineate management zones, and GPS-guided applicators execute variable-rate prescriptions that match nitrogen, phosphorus, and potassium supply to site-specific demand, limiting hotspots of surplus that drive nitrate leaching and nitrous oxide formation (Bhamini *et al*., 2025) [3]. Decision rules incorporate crop stage, weather forecasts, and sensor-derived canopy status to shift portions of total nitrogen into in-season applications, thereby improving synchronization with uptake and reducing immobilization or volatilization after rainfall events. By cutting excess application in high-supply zones and reallocating to deficit areas, these systems

trim fertilizer purchases while preserving yield potential and quality, producing measurable savings per hectare alongside reduced off-field nutrient loading (Bhamini *et al*., 2025) [3]. Integration with remote sensing and IoT platforms further refines prescriptions through iterative updates as conditions evolve.

Additionally, unmanned aerial vehicles and satellite imagery supply rapid, scalable observations that sharpen allocation of water, nutrients, and crop protection across management zones. High-frequency drone flights capture subfield variability at centimeter to decimeter resolution, detecting canopy stress, emergence gaps, and disease foci before yield is compromised, while satellites contribute broad coverage and temporal continuity that anchor season-long adjustment of prescriptions. These image streams, when georeferenced to GNSS and ingested into analytics platforms, produce zone updates that shift irrigation setpoints, reallocate in-season nitrogen, and confine pesticide applications to detected hotspots, thereby reducing overlap and off-target inputs. Importantly, the maturation of imaging sensors and ICT architectures documented in the precision agriculture literature mirrors growing adoption of imagery-driven decision loops that connect sensing to variable-rate actuation (Avola *et al*., 2024) [2]. In fertilization, where patenting activity has concentrated, image-derived vigor and nutrient status maps increasingly inform split-application timing and rate capping in high-supply areas to curtail residuals without constraining attainable yield (Avola *et al*., 2024) [2].

Crop Performance Outcomes

Accordingly, crop performance denotes the combined outcomes of yield quantity, quality attributes that determine marketability, and resilience to biotic and abiotic stressors across variable seasons. Yield remains a central indicator, evaluated as harvested mass per area and often disaggregated by stability measures that track variance across years or management zones to reflect consistent physiological development. Quality is assessed through metrics such as protein, oil content, test weight, size uniformity, and defect rates, which together influence price realization and postharvest efficiency; these attributes respond to timely input synchronization and canopy health maintenance. Resilience, in turn, captures the crop's capacity to maintain function under heat, drought, disease pressure, or nutrient shortfall, with attention to recovery trajectories and the maintenance of critical thresholds for photosynthesis and reproductive success. Producer assessments of precision technologies frequently reference these dimensions—particularly yield gains and cost control—as salient benefits, linking performance indicators to adoption choices (Thompson *et al*., 2018) [13].

In fact, evidence for yield increases under precision farming is strongest where data-driven prescriptions correct spatial misallocation and tighten input timing around sensitive growth stages. Meta-analyses and multi-year farm trials report modest average yield gains—often in the low single digits—when variable-rate seeding and nitrogen are coordinated with canopy and soil diagnostics, with larger responses in fields exhibiting pronounced heterogeneity. Studies linking IoT sensor networks and machine-vision analytics to in-season adjustments show that earlier detection of water or nutrient stress can prevent irreversible losses at flowering or grain fill, translating detection into measurable harvest improvements (Karunathilake *et al*., 2023) [6]. Furthermore, GPS-guided section control reduces overlap that otherwise suppresses stand uniformity, while robotics-enabled precision placement supports consistent emergence and tiller development across management zones (Karunathilake *et al*., 2023) [6]. Although yield responses vary with baseline management, soil texture, and weather, the pattern across trials indicates that precision practices stabilize canopy function and convert avoided stress episodes into incremental, economically meaningful yield gains.

Moreover, precise input management has improved crop quality by tightening spatial uniformity in plant stand, canopy development, and harvest attributes that drive grading outcomes. Variable-rate seeding, irrigation, and nitrogen timing reduce within-field variance in plant size and maturity, which lowers defect rates and improves traits such as test weight, kernel size consistency, and color uniformity that determine market premiums. ICT-integrated control systems coordinate sensors and machinery so that dose, placement, and timing converge on crop physiological thresholds, thereby supporting protein formation in cereals and oil profile targets in oilseeds through stable availability of water and assimilable nitrogen during critical windows (D Andujar, 2023) [4]. In horticultural systems, targeted fertigation and zone-specific canopy management limit overgrowth and nutrient dilution, improving soluble solids and firmness while reducing postharvest shrink, outcomes traceable to synchronized water status and nutrient supply at fruit set. These quality gains complement yield stabilization by shrinking spatial heterogeneity, which simplifies downstream sorting, reduces rejections, and improves contract compliance (D Andujar, 2023) [4].

Furthermore, precision farming enhances crop resilience by enabling early detection of stressors and timely, localized interventions that prevent cascading physiological damage during critical growth stages. Sensor networks and imagery identify pest ingress, disease onset, and water or heat stress at subfield scales, allowing variable-rate irrigation, targeted pesticide deployment, and canopy microclimate adjustments that maintain photosynthetic capacity and reproductive success under volatile weather. Prescription updates informed by short-term forecasts and in-season diagnostics also support staged nutrient supply that sustains root function and tissue integrity, reducing susceptibility windows that pests and pathogens exploit. Although these capabilities depend on data quality, operator skill, and interoperable equipment, the trajectory of lower machinery costs and rising digital proficiency indicates broader feasibility, which is essential for resilience gains to reach small and medium-sized farms (KLEPACKI, 2020) [7]. In contexts where farm structures consolidate and service ecosystems mature, integration of sensing with actuation can stabilize performance against heat spikes, irregular rainfall, and disease pressure (KLEPACKI, 2020) [7].

For example, multi-year trials in variable-rate nitrogen management for winter wheat reported 3–5% yield increases with concurrent improvements in protein uniformity when in-season prescriptions were guided by canopy sensing and GNSS-referenced maps (S *et al*., 2024). A drip-fertigated tomato study using IoT-enabled soil moisture and electrical conductivity sensors documented a 20% reduction in applied water and a 12% rise in marketable yield, attributable to setpoint-based irrigation that maintained

consistent fruit size and firmness during heat events (S *et al*., 2024). In maize, on-farm experiments that paired section control with variable-rate seeding reduced stand overlap by double digits and improved harvestable ears per square meter, translating into stable yields across contrasting soil textures despite irregular rainfall. Similarly, vineyard blocks using remote sensing to target zone-specific irrigation and nitrogen applications achieved narrower distributions of Brix and acidity at harvest, improving contract compliance and reducing sorting losses. Across these cases, measurable gains reflect tighter synchronization of dose, timing, and placement with spatially resolved crop demand (S *et al*., 2024).

Economic and Environmental Impacts

Nevertheless, the economic case for precision farming rests on measurable cost savings from reduced input use, labor efficiency, and improved pass-to-pass accuracy that together raise margin per hectare. Farmers report lower variable costs when section control eliminates overlap, variable-rate prescriptions trim fertilizer and water purchases, and guided traffic reduces fuel and wear, while stabilized yield and quality support higher revenue reliability across seasons. Return on investment emerges from these combined effects and from the option value of better information, which reduces decision error and supports within-season corrections that protect high-value growth stages from irreversible loss. Consistent with economic studies that treat observed adoption as revealed profitability, diffusion patterns across regions and technologies signal that many systems deliver positive net returns under commercial conditions, even as performance varies with heterogeneity, commodity prices, and service costs (Lowenberg-DeBoer, 2019) [8]. Furthermore, projections of continued uptake imply that learning-by-using and competitive service markets will lower per-hectare costs and shorten payback periods as toolchains mature (Lowenberg-DeBoer, 2019) [8]. Additionally, environmental advantages arise when precision systems align input placement with measured field conditions, thereby shrinking the volume of water and agrichemicals transported off-site during storm events. GPS-guided section control and variable-rate irrigation reduce overlap and percolation, while drone-informed hotspot targeting confines pesticide and fertilizer applications to areas of need, which lowers concentrations in surface runoff and tile effluent (Vellingiri *et al*., 2024) [14]. These same adjustments diminish greenhouse gas formation by curbing surplus nitrogen that drives nitrification–denitrification pathways and by reducing fuel use through optimized routes and fewer passes, with sensor feedback preventing unnecessary operations during low-response periods (Vellingiri *et al*., 2024) [14]. Over successive seasons, lower chemical loading and improved moisture regulation support soil microbial activity, aggregate stability, and residue retention, strengthening nutrient cycling and infiltration that buffer fields against erosion. Together, these outcomes link operational precision to broader ecological performance by translating real-time monitoring into site-specific control that reduces losses at the source while maintaining agronomic function.

However, translating technical potential into widespread adoption faces several obstacles that temper the economic and environmental gains outlined above. Upfront investment in GNSS guidance, sensors, variable-rate hardware, and data platforms can strain working capital, with uncertain payback when field heterogeneity is modest or service markets are thin, thereby raising hesitation among producers who weigh costs against perceived benefits (Thompson *et al*., 2018) [13]. Beyond hardware, technological complexity—data calibration, interoperability, prescription generation, and maintenance—demands time and specialized skills that compete with seasonal labor constraints, and errors in configuration can erode expected efficiency improvements. These challenges are compounded by uneven digital infrastructure and fragmented support services, which increase switching costs and limit confidence in multi-vendor toolchains; in turn, producers' heterogeneous perceptions of yield gains, cost savings, and convenience shape willingness to experiment and sustain use over multiple seasons (Thompson *et al*., 2018) [13]. Consequently, targeted training, decision support, and service models that reduce learning burdens become central to lowering adoption thresholds while preserving operational reliability.

Future Prospects and Innovations in Precision Farming

Looking ahead, innovations will concentrate on AI- and machine learning–enabled decision systems that fuse heterogeneous data streams from IoT-connected sensors, imaging platforms, and weather services to generate adaptive, zone-specific prescriptions. Next-generation sensor networks combining hyperspectral, thermal, and soil probes will expand continuous monitoring of water status, nutrient availability, and disease risk, while onboard analytics filter noise, quantify uncertainty, and trigger irrigation, fertigation, or protection only when thresholds are crossed (Mohammed Aarif K. O. *et al*., 2025) [9]. Concurrently, robotics will extend precision beyond mapping and rate control toward autonomous actuation—swarm sprayers, robotic weeders, and harvest assistants—that execute micro-dosed, spatially selective operations synchronized with real-time diagnostics. Edge–cloud architectures will distribute computation so that time-critical control runs locally, whereas model training and cross-season learning proceed centrally, supporting transferable prescriptions across fields and years (Mohammed Aarif K. O. *et al*., 2025) [9]. As these components integrate, interoperability standards, self-calibration routines, and explainable models will be essential to maintain reliability, reduce operator burden, and scale benefits to diverse farm sizes.

Consequently, the convergence of sensing, geolocation, and variable-rate actuation positions precision farming to contribute meaningfully to global food security while aligning production with sustainability targets. By raising output per unit of water, nutrients, and energy, site-specific management can expand effective supply without proportional increases in input demand or land conversion, buffering food systems against climate volatility and resource constraints. Scalable toolchains—remote sensing, ground sensors, and GPS/GIS—translate spatial heterogeneity into actionable prescriptions that curb losses, reduce leaching and emissions, and support consistent yields and quality, which stabilizes supply chains and market availability (Sharma, 2023) [12]. Moreover, precision crop management platforms integrate diverse datasets to coordinate in-season adjustments at field scale, improving reliability of harvest outcomes in smallholder and commercial contexts while reducing off-site impacts that

degrade soils and waterways (Sharma, 2023) [12]. As robotics and automation lower labor bottlenecks and enable micro-dosed, targeted operations, the combined effect is a production system that meets rising demand with tighter resource stewardship and verifiable environmental performance.

Finally, ongoing research and policy initiatives converge on lowering adoption barriers through interoperable platforms, standardized data governance, and targeted support for training and service provision. Public–private programs fund testbeds that integrate IoT sensors, machine vision, and robotics with decision support, enabling demonstration of adaptive prescriptions under commercial conditions while generating open datasets for benchmarking and extension curricula (Karunathilake *et al*., 2023) [6]. Regulatory pathways increasingly reference data standards and audit-ready records, linking conservation payments and tax incentives to verifiable reductions in water use, nutrient residues, and emissions documented by connected equipment. Parallel research agendas emphasize edge–cloud architectures, cybersecurity, and explainable AI to improve reliability and operator trust, with grant schemes prioritizing smallholder-appropriate hardware, connectivity solutions, and modular service bundles that reduce fixed costs (Karunathilake *et al*., 2023) [6]. In combination, procurement guidelines, performance-based subsidies, and interoperability standards create scale economies for vendors and clearer return profiles for producers, accelerating diffusion across heterogeneous farm sizes and cropping systems.

Conclusion

Collectively, the analysis shows that precision farming improves resource use efficiency by aligning water, nutrient, and energy applications with measured crop demand, thereby reducing waste while maintaining agronomic function. These same mechanisms strengthen crop performance through modest but durable yield gains, tighter quality distributions, and greater resilience to episodic stress, outcomes linked to feedback-driven, site-specific decisions across the season. The integration of sensing, geolocation, analytics, and variable-rate actuation translates heterogeneity into timely control, shrinking operational lag and converting avoided stress into marketable output with lower off-site losses. Moreover, emerging AI, robotics, and edge–cloud architectures indicate that these benefits can scale as systems become more interoperable, self-calibrating, and labor-efficient, making reliable performance accessible across farm sizes. Taken together, the evidence suggests a production model that raises output per unit input while curbing environmental burdens, positioning agriculture to meet rising demand under climate and resource constraints with verifiable stewardship outcomes.

References

1. Ahmad SF, Dar AH. Precision farming for resource use efficiency. Springer, 2020. https://doi.org/10.1007/978-981-15-6953-1_4
2. Avola G, Distefano M, Torrisi A, Riggi E. Precision agriculture and patented innovation: State of the art and current trends. World Patent Information,2024:76:102262. https://doi.org/https://doi.org/10.1016/j.wpi.2024.102262
3. Bhamini K, Kumar A, Magrey AH, Jafri SKF, Najmusaqib SLPR, Jan I, *et al*. The role of GIS and GPS in precision fertilization: Optimizing nutrient management for sustainable cropping. Researchgate.Net,2025:8(2):260–267. https://doi.org/10.33545/2618060x.2025.v8.i2d.2574
4. D Andujar. Back to the future: What is trending on precision agriculture? Mdpi.Com, 2023, 13(8). https://www.mdpi.com/2073-4395/13/8/2069
5. Finger R, Swinton SM, El Benni N, Walter A. Precision farming at the nexus of agricultural production and the environment. Annual Review of Resource Economics,2019:11:313–335. https://doi.org/https://doi.org/10.1146/annurev-resource-100518-093929
6. Karunathilake EMBM, Le AT, Heo S, Chung YS, Mansoor S. The path to smart farming: Innovations and opportunities in precision agriculture. Mdpi.Com,2023:13(8):1593. https://doi.org/https://doi.org/10.3390/agriculture13081593
7. Klepacki B. Precision farming as an element of the 4.0 industry economy. Ageconsearch.Umn.Edu, 2020, 2020(3). https://doi.org/https://doi.org/10.22004/ag.econ.308224
8. Lowenberg-DeBoer J. The economics of precision agriculture. Burleigh Dodds Science Publishing, 2019. https://doi.org/10.1201/9781351114592-22
9. Mohammed Aarif KO, Afroj Alam, Yousuf Hotak. Smart sensor technologies shaping the future of precision agriculture: Recent advances and future outlooks. Journal of Sensors, 2025, 2025(1). https://doi.org/https://doi.org/10.1155/js/2460098
10. Raj EFI, Appadurai M, Athiappan K. Precision farming in modern agriculture. Springer, 2021. https://doi.org/10.1007/978-981-16-6124-2_4
11. SSK Moinuddin N, Belagalla N, Srinatha TN, Abhishek GJ, Kumar V, Tiwari A, *et al*. Revolutionizing agriculture: innovative techniques, applications, and future prospects in precision farming. Journal of Scientific Research and Reports,2024:30(8):405–419. https://doi.org/10.9734/jsrr/2024/v30i82263
12. Sharma S. agriculture: Reviewing the advancements technologies and applications in precision agriculture for improved crop productivity and resource management. Rfna.Com.My,2023:4(2):45–49. https://doi.org/10.26480/rfna.02.2023.45.49
13. Thompson NM, Bir C, Widmar DA, Mintert JR. Farmer perceptions of precision agriculture technology benefits. Journal of Agricultural and Applied Economics,2018:51(1):142–163. https://doi.org/10.1017/aae.2018.27
14. Vellingiri A, Kokila R, Nisha P, Kumar M, Chinnusamy S, Boopathi S, *et al*. Harnessing GPS, sensors, and drones to minimize environmental impact: precision agriculture. IGI Global Scientific Publishing, 2024. https://doi.org/10.4018/979-8-3693-5498-8.ch004
15. Zaman Q. Precision agriculture: Evolution, insights and emerging trends, 2023. books.google.com. https://books.google.com/books?hl=en&lr=&id=hmilEAAAQBAJ&oi=fnd&pg=PP1&dq=historical+evolution+of+precision+agriculture&ots=UUnCWGopzK&sig=3Qg3aOTtcIK0u5kxECpXS0KJ-ug

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Impact of integrated nutrient management on crop yield, soil health, and sustainability

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Abstract
Consequently, this essay examines Integrated Nutrient Management (INM) as a coordinated approach that combines organic amendments, mineral fertilizers, biofertilizers, and site-specific diagnostics to meet crop nutrient demands while maintaining ecological balance. INM is defined here as the planned integration of diverse nutrient sources and decision tools to optimize timing, placement, and quantity, thereby aligning productivity goals with resource stewardship. The analysis considers how INM improves crop yield through balanced nutrient supply, improved nutrient-use efficiency, and greater resilience to climatic and edaphic variability. It also evaluates effects on soil health, including organic matter dynamics, biological activity, aggregation, and nutrient cycling, which underpin sustained fertility across seasons. Beyond field performance, the discussion addresses environmental and economic sustainability by assessing reductions in nutrient losses, mitigation of greenhouse gas emissions, input-use efficiency, and cost stability for farmers, setting the stage for evidence-based evaluation across yield, soil, and sustainability outcomes.

Keywords: Integrated nutrient management (inm), crop productivity, soil fertility, sustainable agriculture and nutrient use efficiency

Introduction

Moreover, Integrated Nutrient Management (INM) refers to the coordinated use of organic inputs, mineral fertilizers, biological inoculants, and diagnostic tools to supply nutrients in synchrony with crop demand. It has gained relevance in modern agriculture as production systems contend with finite fertilizer resources, climate variability, and the need to curtail nutrient losses that degrade water quality and air. By aligning timing, placement, and nutrient forms, INM aims to sustain yields while maintaining soil processes that support long-term productivity and buffering capacity. The approach is operationally flexible, allowing site-specific combinations that respond to soil constraints, cropping sequences, and local resource availability without sacrificing agronomic rigor. This essay examines three connected domains: first, the effects of INM on crop yield through balanced supply and improved nutrient-use efficiency; second, the influence on soil health via organic matter turnover, aggregation, and biotic activity; and third, environmental and economic sustainability outcomes associated with reduced losses and steadier input costs.

Understanding Integrated Nutrient Management

Furthermore, Integrated Nutrient Management (INM) is the deliberate coordination of organic materials, mineral fertilizers, and biological agents to match crop demand across time and space while maintaining soil functions. Its principles include balancing nutrient budgets, synchronizing release with phenological stages, and using diagnostics to guide rate, source, timing, and placement, thereby aligning agronomic goals with environmental safeguards (Selim, 2020) [15, 16]. Core components span composts, manures, crop residues, green manures, and cover crops that build organic carbon, alongside mineral inputs targeted to specific deficiencies identified through soil testing, and microbial inoculants such as mycorrhizae and nitrogen-fixing bacteria that improve acquisition and cycling (Kushwah *et al*., 2024) [10]. The rationale for integration rests on complementarity: organic inputs improve structure, water retention, and microbial activity, while mineral sources provide immediately available nutrients that prevent shortfalls during peak demand, and inoculants strengthen rhizosphere interactions. In practice, crop rotation and diversification extend these gains by distributing nutrient extraction, disrupting pest cycles, and stabilizing soil fertility across seasons (Kushwah *et al*., 2024) [10].

Furthermore, nutrient management practices trace a trajectory from nutrient recycling in traditional mixed farming to the standardized use of synthetic fertilizers during the Green Revolution, and finally toward integration as limitations of single-source approaches became apparent. Early systems relied on manures, composts, and legume rotations that sustained soil organic matter but could not always meet rapidly increasing nutrient demand under intensified cropping. The widespread adoption of mineral fertilizers delivered immediate yield gains, yet imbalances in nutrient ratios, declining soil biological activity, and externalities such as runoff prompted recalibration of practice and policy. In response, INM emerged by recombining organic amendments, targeted chemical inputs, and biofertilizers with diagnostic tools, thereby linking short-term nutrient availability to long-term soil function and system resilience (Panta & Parajulee, 2021) [11]. This historical shift reflects a pragmatic synthesis: integration reduces exclusive dependence on chemical inputs while improving microbial activity and soil properties that support stable productivity across seasons (Panta & Parajulee, 2021) [11].

Additionally, common strategies within Integrated Nutrient Management include crop rotation, which distributes

nutrient extraction across species and phases, and green manuring, where leguminous cover crops fix nitrogen and supply labile carbon that supports microbial turnover. Composting stabilizes organic residues into humified fractions that release nutrients gradually while improving aggregation and water retention, thereby moderating seasonal variability in nutrient supply. The use of biofertilizers—such as rhizobia, Azotobacter, phosphate-solubilizing bacteria, and arbuscular mycorrhizae—enhances nutrient acquisition pathways and can reduce dependence on mineral inputs during critical growth stages. Operationally, these techniques are linked through diagnostics that align nutrient release with phenology and through decision support that coordinates application timing, residue management, and inoculant viability, mirroring integrated decision cycles adopted in adjacent agricultural management frameworks (Dara, 2019) [4]. Moreover, farmer training and information-sharing networks sustain the continuity of these practices by standardizing protocols for compost maturity, inoculant quality control, and rotation planning, thereby improving field-level consistency and scaling across production systems (Dara, 2019) [4].

Impact of INM on Crop Yield

Consequently, empirical comparisons across crops indicate that Integrated Nutrient Management consistently raises yields relative to mineral-only fertilization through complementary supply and synchronized release. A meta-level review reports yield gains from 1.3% to 66.5% in rice, wheat, and soybean under INM, attributed to improved nutrient availability and better soil physical conditions that support root growth and water capture (Paramesh *et al*., 2023) [12]. Field-level evidence in maize grown on acid Inceptisols shows that combining NPK with farmyard manure or vermicompost, biofertilizers, and liming improves root density and nutrient uptake, with lime serving as an essential amendment to correct acidity constraints (Ghosh *et al*., 2019) [6, 7]. Notably, plots receiving chemical fertilizer without an organic component suffered a 53% yield reduction, highlighting the risk of nutrient imbalances and poor rhizosphere function when rapid-release sources are used alone (Ghosh *et al*., 2019) [6, 7]. Together, these findings show that integrated packages outperform conventional programs by aligning immediate nutrient supply with sustained soil-mediated support for growth (Paramesh *et al*., 2023) [12].

Moreover, the productivity gains observed under Integrated Nutrient Management arise from process-level improvements in nutrient solubility, rhizosphere transport, and root acquisition efficiency. Organic amendments supply labile carbon and functional groups that chelate cations and buffer pH, increasing the availability of phosphorus, micronutrients, and ammonium while improving water retention that supports mass flow to roots (Kushwah *et al*., 2024) [10]. Concurrently, mineral fertilizers targeted by soil testing prevent transient deficits during peak demand, ensuring adequate ionic gradients for uptake and reducing antagonisms that occur when single nutrients are applied without balance (Kushwah *et al*., 2024) [10]. Biofertilizers strengthen these effects: mycorrhizal hyphae extend the depletion zone and accelerate phosphorus and zinc uptake, whereas nitrogen-fixing and phosphate-solubilizing bacteria contribute ammonium and mobilized orthophosphate, thereby lowering the energetic cost of acquisition. Finally, crop rotation and cover crops maintain continuous nutrient cycling and root exudation, preserving microbial biomass and enzyme activity that sustain mineralization across seasons and stabilize supply during critical phenological stages (Kushwah *et al*., 2024) [10].

In addition, optimal yield responses under Integrated Nutrient Management arise when nutrient supply is balanced across macronutrients and micronutrients while simultaneously curbing pathways of loss such as leaching, volatilization, and runoff. Balancing sources through calibrated combinations of organic and mineral inputs aligns supply with crop demand, preventing antagonisms and hidden hunger that depress photosynthate allocation to grain; concurrently, organic amendments increase cation exchange capacity and moisture retention, moderating concentration peaks that otherwise drive nitrate movement beyond the root zone (Chejara *et al*., 2021) [2, 3]. Reduced losses maintain a steadier root-zone concentration, sustaining uptake kinetics during critical phenophases and preserving energy for growth rather than stress responses associated with deficiency–surplus cycles. Moreover, recycling on-farm residues and manures supplies slowly mineralizing pools that dampen temporal variability and decrease reliance on high single-dose applications, which are more prone to gaseous and hydraulic export from fields (Chejara *et al*., 2021) [2, 3]. These dynamics translate into higher agronomic efficiency, allowing lower applied doses to deliver comparable or greater yield through improved recovery and conversion.

For example, multi-season field trials in acidic Inceptisols showed that maize receiving a coordinated package of NPK, farmyard manure or vermicompost, biofertilizers, and lime produced higher ear length, kernels per row, and grain yield than mineral-only controls, indicating that integration corrected both nutrient supply and edaphic constraints (Ghosh *et al*., 2019) [6, 7]. The inclusion of lime was decisive because it improved rhizosphere pH and exchange sites, which, together with organic inputs, raised root density and sustained uptake during peak demand phases (Ghosh *et al*., 2019) [6, 7]. Notably, the same experiments reported a 53% yield reduction where chemical fertilizers were applied without any organic amendment, demonstrating that unbuffered soluble inputs can depress performance in low-buffer soils even when nominal nutrient rates are adequate (Ghosh *et al*., 2019) [6, 7]. These outcomes align with the preceding process analysis by linking yield gains to synchronized availability, moderated loss pathways, and improved root–soil contact. They also provide a template for rice–wheat systems on marginal soils, where calibrated liming and organic additions can stabilize returns while maintaining fertilizer response.

However, consistent yield gains under Integrated Nutrient Management are not guaranteed because variability in the quality and decomposition rate of organic materials can desynchronize nutrient release from crop demand, especially under fluctuating moisture and temperature. Heterogeneous carbon-to-nitrogen ratios, variable lignin content, and uncertain microbial activity alter mineralization trajectories, requiring frequent calibration of mineral supplements to avoid temporary deficits or surpluses during peak uptake. Labor and management demands also constrain outcomes: composting, residue handling, and properly timed applications add seasonal workload that smallholders may

not meet during critical windows, thereby reducing the effectiveness of synchronized supply. Moreover, limited extension support, uncertain access to reliable inoculants, and fragmented markets for quality organic inputs create input inconsistency and risk that discourage sustained adoption and learning-by-doing needed to refine site-specific protocols (Tiemann & Douxchamps, 2023) [17]. These technical and institutional constraints interact with cost structures and price signals, so that even agronomically sound packages may not be implemented at scale without supportive research, financing, and market arrangements (Tiemann & Douxchamps, 2023) [17].

Influence of INM on Soil Health

Meanwhile, Integrated Nutrient Management (INM) improves soil fertility by building organic matter pools that support aggregate stability, pore continuity, and water retention, thereby creating conditions that sustain nutrient availability across seasons (Selim, 2020) [15, 16]. The combined application of organics with calibrated mineral fertilizers and biofertilizers increases soil organic carbon and cation exchange capacity, moderates acidity through liming, and raises base saturation, which together strengthen nutrient buffering and reduce transient deficits (Ghosh *et al*., 2019) [6, 7]. Enhanced structure and higher water-holding capacity lower bulk density and improve aeration, facilitating microbial turnover that drives mineralization of nitrogen and mobilization of phosphorus and micronutrients into plant-available forms (Ghosh *et al*., 2019) [6, 7]. These biological feedbacks are reinforced as organic inputs supply energy substrates for microbes, allowing steady enzyme activity and rhizosphere interactions that maintain cycling even under variable moisture and temperature (Selim, 2020) [15, 16]. Consequently, INM creates a self-reinforcing soil system in which physical quality, microbial processes, and chemical reserves jointly sustain fertility and stabilize crop response.

Furthermore, Integrated Nutrient Management stimulates soil microbial activity and biodiversity by supplying diverse carbon substrates and habitat structure through organic amendments while providing targeted mineral nutrients that prevent metabolic bottlenecks. Manures, composts, and residue incorporation increase particulate and dissolved organic matter, fueling heterotrophic growth and enzyme production, whereas improved aggregation and porosity protect microbial microhabitats from desiccation and predation, supporting a richer assemblage of decomposers, mutualists, and nitrifiers (Paramesh *et al*., 2023) [12]. Biofertilizers add functional groups such as rhizobia, Azotobacter, phosphate-solubilizing bacteria, and arbuscular mycorrhizae, which expand nutrient acquisition pathways, intensify rhizosphere signaling, and create complementary niches that stabilize community structure during seasonal fluctuations. These interactions reduce the amplitude of nutrient oscillations by coupling mineralization to crop phenology, thereby maintaining steady root-zone availability while lowering the risk of opportunistic blooms associated with unbalanced inputs (Paramesh *et al*., 2023) [12]. As a result, microbial biomass, diversity, and activity co-vary with improved physical conditions and carbon supply, strengthening nutrient cycling, resilience to stress, and long-term soil function.

As a result, the integrated use of organic amendments, biofertilizers, and calibrated mineral inputs reduces soil degradation by improving aggregation and cation exchange capacity, which curtails crusting, compaction, and surface sealing that precede erosive losses (Panta & Parajulee, 2021) [11]. Compared to exclusive chemical fertilization, INM builds soil organic carbon and microbial biomass that strengthen aggregate stability and pore continuity, thereby lowering runoff velocity and sediment detachment on sloping and intensively tilled fields (Panta & Parajulee, 2021) [11]. Increased biological activity also accelerates residue decomposition into stable fractions, raising water infiltration and moisture retention, which in turn dampens erosive episodes during high-intensity rainfall. Concurrently, balanced nutrient supply and improved buffering reduce nutrient depletion by maintaining root-zone availability and moderating leaching and volatilization that occur under high, unbalanced soluble applications. Evidence from synthesis work indicates that these physical and biological gains coincide with improved chemical status, producing fields that retain nutrients longer and lose less soil mass than systems reliant on mineral fertilizers alone (Panta & Parajulee, 2021) [11].

Additionally, Integrated Nutrient Management stabilizes soil pH and mitigates salinity and toxicity by coordinating organic inputs, targeted mineral amendments, and microbial inoculants to regulate ionic balances and buffering capacity. Organic materials contribute functional groups and carbonate equivalents that neutralize acidity, increase cation exchange capacity, and complex aluminum and manganese, thereby reducing root toxicity while moderating rapid shifts that follow heavy soluble fertilizer use (Kushwah *et al*., 2024) [10]. Where sodicity or salinity pressures exist, gradual nutrient release from composts and manures lowers osmotic stress, while balanced mineral additions avoid sodium accumulation by maintaining adequate calcium, magnesium, and potassium on exchange sites to sustain flocculation and infiltration. Biofertilizers, including mycorrhizae and nitrogen-fixing bacteria, improve nutrient uptake efficiency at moderate concentrations, allowing lower salt loads per unit yield and reducing the frequency of high-conductivity applications that destabilize pH and induce ion antagonisms (Kushwah *et al*., 2024) [10]. In turn, crop rotation and diversification distribute extraction patterns, limit chloride and sodium carryover, and permit periodic corrective liming or gypsum scheduling to maintain favorable reaction conditions across seasons.

Environmental and Economic Sustainability of INM

Consequently, Integrated Nutrient Management (INM) delivers environmental gains by aligning nutrient inputs with crop demand, which curtails surplus nitrogen and phosphorus prone to leaching and runoff into waterways. By substituting portions of synthetic fertilizers with organic sources and calibrating mineral applications, INM decreases reactive nitrogen accumulation, a change linked to lower nitrous oxide and nitric oxide emissions and improved yield-scaled emission intensity in rice systems managed with ground cover and water-saving practices (Yao *et al*., 2018) [18]. Reduced emission factors in these systems indicate that synchrony and source blending diminish gaseous losses while sustaining grain output, thereby limiting atmospheric pollution without compromising production (Yao *et al*., 2018) [18]. Parallel gains arise from recycling agricultural wastes into composts and manures, which replaces external inputs, stabilizes soil structure that

retains nutrients, and lowers pollution risk, while also reducing total nutrient costs for farmers through on-farm resource use (Chejara *et al*., 2021) [2, 3]. These adjustments support ecosystem services by improving soil carbon stocks, water infiltration, and microbial functioning that regulate nutrient cycling (Chejara *et al*., 2021) [2, 3].

Moreover, the economic case for Integrated Nutrient Management (INM) rests on reduced expenditure for mineral fertilizers through partial substitution with on-farm organics and improved nutrient-use efficiency that lowers application rates without depressing output. Input cost savings are reinforced when calibrated blends avert quality penalties—especially in fruit systems where excess inorganic fertilization reduces marketable grade and price—thereby protecting revenue streams while maintaining agronomic performance (Kumari, 2025) [9]. Yield stability adds further value by smoothing interseasonal variability, since gradual nutrient release from composts and manures sustains uptake during weather fluctuations, reducing the risk of shortfalls that trigger emergency purchases or lost sales. These effects compound over time as soil carbon, cation exchange capacity, and microbial activity strengthen recovery efficiency, enabling smaller incremental doses to achieve target yields and lowering the cost per unit of production. Consequently, multi-year profitability improves through a combination of lower variable costs, steadier yields, and reduced postharvest losses linked to more consistent product quality and size distributions (Kumari, 2025) [9].

Furthermore, the scalability and adaptability of Integrated Nutrient Management (INM) arise from its modular design, which allows tailored blends of organic materials, mineral fertilizers, and biofertilizers to match resource endowments and climatic constraints across agro-ecological zones. In rainfed semi-arid systems, priority can be given to composts and residue mulches that improve water retention and buffer nutrient release, while targeted mineral supplements address episodic deficits during short, intense growing periods (Selim, 2020) [15, 16]. In irrigated rice–wheat belts, synchronized dosing guided by diagnostics can integrate manures and green manures to stabilize soil structure, with calibrated mineral inputs maintaining yield targets under high-cropping intensity (Selim, 2020) [15, 16]. Smallholders can rely on on-farm residues and seasonal legume covers to reduce cash expenditures, whereas commercial farms can deploy precision placement and quality-controlled inoculants to improve recovery efficiency within mechanized schedules. Policy and extension frameworks further support scaling by standardizing testing services, compost quality benchmarks, and training that translate INM principles into locally actionable protocols for diverse farming systems.

In addition, Integrated Nutrient Management (INM) contributes to climate change mitigation by increasing soil organic matter and microbial activity that support carbon stabilization while lowering emission intensity through improved nutrient-use efficiency. Long-term INM in acidic Inceptisols raised dehydrogenase and phosphomonoesterase activities and increased soil organic matter, conditions that favor carbon accrual in aggregates and reduce the need for high mineral fertilizer doses associated with nitrous oxide release (Patra *et al*., 2020) [13]. These biophysical changes complement adaptation by improving water-holding capacity, aggregation, and root-zone nutrient buffering, which sustain crop performance during drought and high-rainfall variability common under shifting climates. Moreover, diversified nutrient sources and biofertilizers expand acquisition pathways, allowing crops to maintain uptake at moderate concentrations, thereby reducing osmotic stress and the probability of loss spikes during extreme events while preserving yield stability. By strengthening microbial-mediated cycling and maintaining a steadier nutrient supply, INM builds soil functions that both sequester carbon and buffer production risks under climate uncertainty (Patra *et al*., 2020) [13].

Barriers and Challenges to INM Adoption

Nevertheless, widespread adoption of Integrated Nutrient Management (INM) is constrained by intertwined knowledge, resource, and policy obstacles that vary across farm types and infrastructure contexts. Surveys indicate that both adopters and nonadopters experience barriers, including uncertainty about performance, limited time for learning, and administrative burdens linked to compliance or documentation, suggesting that motivation alone does not remove adoption frictions (Rudnick *et al*., 2023) [14]. Resource constraints remain pronounced: smaller farms face cash-flow limits for composting equipment, testing services, and quality inoculants, whereas larger parcels with microirrigation and advisory networks are more likely to implement practices such as split applications and ET-based scheduling that support INM's synchrony objectives (Khalsa *et al*., 2022) [8]. Information bottlenecks further impede progress when field-relevant guidance is not delivered through trusted local channels, making extension and pest control advisors crucial conduits for context-specific diagnostics and scheduling. Finally, policy frameworks that reward yield but not nutrient-use efficiency, and fragmented quality standards for organics, weaken incentives to coordinate sources and timing at scale (Rudnick *et al*., 2023) [14].

To address these challenges, a coordinated policy package should combine strengthened extension services, targeted subsidies, and iterative farmer training that builds decision capacity and confidence. Extension programs need to deliver site-specific diagnostics, split-application scheduling, and quality standards for composts and inoculants while engaging trusted advisors, since adoption is shaped by perceived efficacy and social learning processes central to behavior change (Gao & Arbuckle, 2021) [5]. Subsidies should reduce upfront costs for soil testing, composting infrastructure, lime, and biofertilizers, and be structured as performance-based incentives that reward nutrient-use efficiency and verified reductions in loss pathways rather than volume of inputs applied. Training curricula ought to develop self-efficacy through hands-on trials, peer mentoring, and decision tools that reflect local rotations and risk profiles, with modules attuned to age, acreage, insurance participation, and economic pressure that predict adoption heterogeneity (Gao & Arbuckle, 2021) [5]. Finally, policy alignment across crop insurance, procurement, and environmental compliance can link premium discounts and market access to documented INM plans and monitoring, reinforcing durable practice change.

Future Prospects and Innovations in INM

Subsequently, future Integrated Nutrient Management will be shaped by precision tools that align nutrient release with

rapidly shifting field conditions, reducing exposure to weather-driven yield volatility. Variable-rate application guided by proximal sensors and satellite imagery can tailor nitrogen and phosphorus to canopy status and soil heterogeneity, while closed-loop controllers coordinate split doses with evapotranspiration and soil moisture dynamics. Digital monitoring systems that combine in situ ion-selective probes, low-cost spectrometry, and machine learning can forecast short-term nutrient deficits and recommend adjustments prior to stress, a capability that is especially relevant as temperature and precipitation extremes depress yields in many regions (Beillouin *et al*., 2020) [1]. Novel biofertilizers—engineered consortia of mycorrhizae, diazotrophs, and phosphate-mobilizers—paired with carriers that protect viability during storage and field fluctuations could maintain acquisition pathways when heat or drought constrains mineralization (Beillouin *et al*., 2020) [1]. Finally, decision platforms integrating weather nowcasts, seasonal outlooks, and crop models would schedule amendments to avoid loss-prone windows, improving nutrient-use efficiency and resilience.

Finally, advancing Integrated Nutrient Management (INM) requires sustained research programs that co-develop site-specific protocols with farmers while generating comparative evidence on yield stability, nutrient-use efficiency, and soil recovery under diverse constraints. Public research should prioritize long-term trials that quantify decomposition dynamics of local organics, performance of biofertilizers in variable climates, and cost–benefit profiles that reflect labor peaks and market volatility, thereby reducing uncertainty that currently dampens adoption (Tiemann & Douxchamps, 2023) [17]. Education and extension must translate these findings into modular training on diagnostics, split applications, compost quality control, and inoculant handling, delivered through trusted local advisors and peer networks that support iterative learning and adaptive management. International cooperation can align funding with problem-driven research, harmonize compost and inoculant standards, and revise trade rules to recognize the additional costs of sustainability-focused management, fostering cross-border diffusion of validated INM packages (Tiemann & Douxchamps, 2023) [17]. Together, these actions build credible evidence, stable incentives, and institutional capacity needed for durable, large-scale uptake.

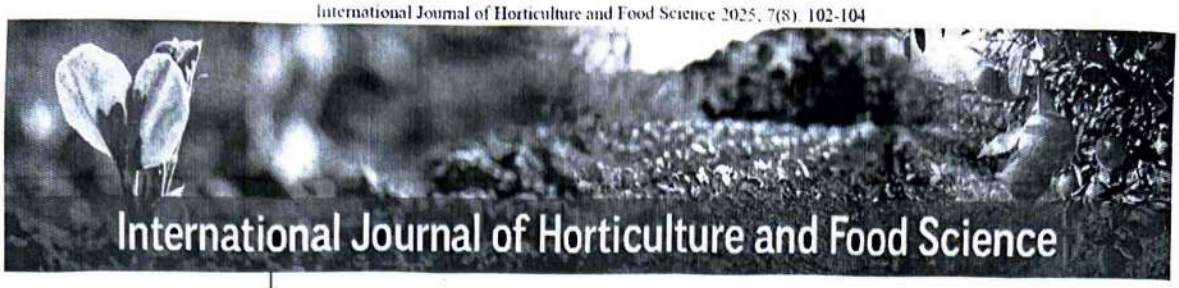
Conclusion

Altogether, the evidence presented shows that Integrated Nutrient Management (INM) raises crop yield by synchronizing nutrient supply with phenology, aligning immediate mineral availability with the structural and biological support derived from organics and biofertilizers. This coordinated strategy stabilizes soil health through increases in organic carbon, improved aggregation, higher cation exchange capacity, and resilient microbial communities that maintain mineralization and nutrient buffering across seasons. Environmental outcomes follow from reduced leaching, volatilization, and runoff, alongside lower emission intensity and greater carbon retention, while economic performance improves through reduced input requirements, steadier yields, and protection of product quality. Although adoption faces knowledge, infrastructure, and policy barriers, modular design and precision tools demonstrate a feasible path for scaling across farm sizes and agro-ecologies. Therefore, INM stands as a practical foundation for future agriculture by coupling productivity with resource stewardship, offering a durable route to maintain food supply while safeguarding soils and minimizing externalities.

References

1. Beillouin D, Schauberger B, Bastos A, Ciais P, Makowski D. Impact of extreme weather conditions on European crop production in 2018. Philosophical Transactions of the Royal Society B,2020:375(1810):20190510. https://doi.org/10.1098/rstb.2019.0510
2. Chejara S, Malik K, Rani M, Bhardwaj AK. Integrated nutrient management: Concept, constraints, and advantages for a sustainable agriculture. Anrcm.Org,2021a:2(2):85–94. https://doi.org/10.51396/anrcm.2.2.2021.85-94
3. Chejara S, Malik K, Rani M, Bhardwaj AK. Integrated nutrient management: Concept, constraints, and advantages for a sustainable agriculture. Anrcm.Org,2021b:2(2):85–94. https://doi.org/10.51396/anrcm.2.2.2021.85-94
4. Dara SK. The new integrated pest management paradigm for the modern age. Journal of Integrated Pest Management,2019:10(1):12. https://doi.org/10.1093/jipm/pmz010
5. Gao L, Arbuckle J. Examining farmers' adoption of nutrient management best management practices: a social cognitive framework. Agriculture and Human Values,2021:39(2):535–553. https://doi.org/10.1007/s10460-021-10266-2
6. Ghosh D, Mandal M, Das S, Pattanayak SK. Effect of integrated nutrient management on yield attributing characters and productivity of maize in acid Inceptisols. Researchgate.Net, 2019. https://www.researchgate.net/profile/Shreya-Das-3/publication/339313916_Effect_of_integrated_nutrient_management_on_yield_attributing_characters_and_productivity_of_maize_in_acid_Inceptisols/links/5e4ae403a6fdccd965aedac1/Effect-of-integrated-nutrient-management-on-yield-attributing-characters-and-productivity-of-maize-in-acid-Inceptisols.pdf
7. Ghosh D, Mandal M, Dey R, Kumar Pattanayak S. Effect of integrated nutrient management on fertility status of soil in acid inceptisols. Researchgate.Net,2019:7(6):1318–1322. https://www.researchgate.net/profile/Deblina-Ghosh-2/publication/344237967_Effect_of_integrated_nutrient_management_on_fertility_status_of_soil_in_acid_inceptisols/links/5f5f620a299bf1d43c01e930/Effect-of-integrated-nutrient-management-on-fertility-status-of-soil-in-acid-inceptisols.pdf
8. Khalsa SDS, Rudnick J, Lubell M, Sears M, Brown P H. Linking agronomic and knowledge barriers to adoption of conservation practices for nitrogen management. Frontiers in Agronomy, 2022, 4. https://doi.org/10.3389/fagro.2022.915378
9. Kumari M. Integrated nutrient management. researchgate.net, 2025. https://www.researchgate.net/profile/Kamlesh-Yadav-12/publication/396317993_Frontiers_For_Sustainable_Agriculture_Editors/links/68e6a7f6f3032e2b4be78a6a/

Frontiers-For-Sustainable-Agriculture-Editors.pdf#page=77
10. Kushwah N, Billore V, Sharma OP, Singh D, Chauhan APS. Integrated Nutrient management for optimal plant health and crop yield. Plantarc.Com; plantarc.com, 2024. https://doi.org/https://doi.org/10.51470/PSA.2023.8.2.10
11. Panta S, Parajulee D. Integrated nutrient management (INM) in soil and sustainable agriculture. International Journal of Applied Sciences and Biotechnology,2021:9(3):160–165. https://doi.org/10.3126/ijasbt.v9i3.39275
12. Paramesh V, Kumar RM, Rajanna GA, Gowda S, Nath AJ, Madival Y, *et al*. Integrated nutrient management for improving crop yields, soil properties, and reducing greenhouse gas emissions. Frontiers in Sustainable Food Systems, 2023, 7. https://doi.org/10.3389/fsufs.2023.1173258
13. Patra A, Sharma VK, Purakayastha TJ, Barman M, Kumar S, Chobhe KA, *et al*. Effect of long-term integrated nutrient management (INM) practices on soil nutrients availability and enzymatic activity under acidic Inceptisol of North-Eastern region of …. Communications in Soil Science and Plant Analysis,2020:51(9):1137–1149. https://doi.org/10.1080/00103624.2020.1751185
14. Rudnick J, Khalsa SDS, Lubell M, Leinfelder-Miles M, Gould K, Brown PH, *et al*. Understanding barriers to adoption of sustainable nitrogen management practices in California. Taylor Francis,2023:78(4):347–363. https://doi.org/10.2489/jswc.2023.00109
15. Selim MM. Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. International Journal of Agronomy, 2020a, 2020(1). https://doi.org/https://doi.org/10.1155/2020/2821678
16. Selim MM. Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. International Journal of Agronomy, 2020b, 2020(1). https://doi.org/https://doi.org/10.1155/2020/2821678
17. Tiemann T, Douxchamps S. Opportunities and challenges for integrated smallholder farming systems to improve soil nutrient management in Southeast Asia. World Development Sustainability,2023:3:100080. https://doi.org/10.1016/j.wds.2023.100080
18. Yao Z, Zheng X, Wang R, Liu C, Lin S, Butterbach-Bahl K, *et al*. Benefits of integrated nutrient management on N2O and NO mitigations in water-saving ground cover rice production systems. Science of The Total Environment,2018:646:1155–1163. https://doi.org/10.1016/j.scitotenv.2018.07.393



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The effect of micronutrients and GA_3 on growth and yield of tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan

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Abstract
This study was conducted with the objective to determine the effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan and an experiment was conducted at the horticultural farm, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized block design (RBD) with seven treatments replicated three times comprising GA_3 and micronutrients with control i.e. T_1: GA_3 (50ppm), T_2: GA_3 (100ppm), T_3: $ZnSO_4$ (0.5%), T_4: $ZnSO_4$ (1%), T_5: Boric acid (50ppm), T_6: Boric acid (100ppm) and T_7: Control. Significantly, differences were found for plant growth parameters *viz*. plant height (cm), number of branches plant^{-1}, number of flower cluster^{-1}, number of cluster plant^{-1}, was recorded highest in T_2: GA_3 (100ppm). The treatment T_2: GA_3 (100ppm) was also found best in early days to 50% flowering, days to first fruit set and yield attributes *viz*., no. of fruit per cluster, no. of fruit plant^{-1}, average fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg) and fruit yield (q/ha) in tomato cv. Kashi Chayan. It is revealed that the use of GA_3 at the concentration of 100ppm, considerably increased the vegetative growth parameters and significantly increased growth and yield of tomato.

Keywords: Micronutrients, GA_3, Growth and Yield

Introduction
Tomato (*Lycopersicon esculentum* Mill.) is a member of the Solanaceae family and is a diploid species with a chromosome number of 2n=24. Originally native to Peru and Mexico, it is now widely cultivated across the globe due to its ability to thrive in a variety of soil types and climates (Gerszberg *et al.*, 2015) [4]. The top tomato-producing countries include China, the United States, India, Egypt, Turkey, Iran, Mexico, Brazil, and Indonesia [FAO, 2022]. Tomato is a warm-season crop that is sensitive to cold temperatures (Afshari *et al.*, 2014) [1]. It can be cultivated in both the wet and dry seasons, provided the annual rainfall ranges from 60 to 150 cm. However, excessive rainfall during its growth period can be detrimental to the plant. Micronutrients play a crucial role in plant processes, and foliar application of these nutrients can enhance both the quality and yield of tomatoes (Ali *et al.*, 2012) [2] by boosting the photosynthetic activity in green plants (Singh and Tiwari, 2013) [13]. Micronutrients management is essential to boost the crop production and also increased the fruits quality. Boron and zinc important micronutrient for quality tomato fruit production. Zinc regulates growth and also promotes balanced sugar consumption and Boron helps to providing some nutrients and essential for proper development of their fruits and seeds. Gibberellic acid is a key growth regulator with various potential applications for altering plant growth, yield, and yield-related traits (Rafeekher). Considering the facts, the current study aims to examine the effects of Micronutrients and GA_3 on the growth and yield of tomato.

Materials and Methods
A field experiment entitled " The effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan" was conducted at the experimental field of Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized

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Synthesis of valuable oxygen-containing compounds; highly enantioselective oxidation; stereoselective synthesis; Green synthesis

OXIDATIVE DEPROTECTION OF TETRAHYDROPYRANYL ETHERS WITH *in situ* GENERATED TETRAETHYLAMMONIM SUPEROXIDE

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ABSTRACT

An efficient procedure has been developed for the oxidative deprotection of tetrahydropyranyl ethers to the corresponding carbonyl compounds under the mild reaction conditions of *in situ* generated tetraethylammonium superoxide.

Keywords: tetrahydropyranyl ethers, deprotection, tetraethylammonium superoxide.

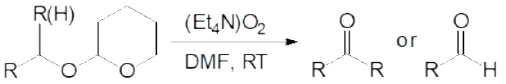
AIMS AND BACKGROUND

Tetrahydropyranyl (THP) ethers are widely used as protecting groups for alcohols in synthetic chemistry[1–3]. THP ether can be easily synthesised from a variety of hydroxyl- compounds by acid catalysed reaction with 3,4-dihydro-2H-pyran[4]. Moreover, THP ethers are insensitive to various reagents and conditions such as base, oxidative agents, Grignard reagent, alkylating agents and many more[5]. A variety of methods for the selective removal of THP ethers have been developed, but the direct synthesis of carbonyl compounds from tetrahydropyranyl ethers is a useful practical achievement and only few reports are available[5–10].

In light of the above and as a part of the ongoing research on superoxide chemistry[11], we describe herein our result on the reactivity of *in situ* generated tetraethylammonium superoxide (Et_4NO_2) with different tetrahydropyranyl ethers under nonaqueous conditions at room temperature, affording the corresponding carbonyl compounds (Scheme 1).

* For correspondence.

Scheme 1



EXPERIMENTAL

Potassium superoxide and tetraethylammonium bromide were procured from E. Merck and were used as received. Dry DMF of Aldrich, was stored over molecular sieves (4 Å) prior to use. The other reagents and solvents were of A.R. grade. Tetrahydropyranyl ethers were prepared according to a literature procedure[12]. IR spectra were recorded on a Perkin Elmer FT-IR spectrometer. ^{1}H NMR spectra were recorded on a JEOL ECZ 500R FT-NMR spectrometer and the chemical shifts are expressed as δ (ppm), using TMS as an internal reference.

General procedure. A mixture of potassium superoxide (1.13 g, 0.016 mol) and tetraethylammonium bromide (1.68 g, 0.008 mol) (weighted under nitrogen atmosphere using an atmosbag) in dry dimethylformamide (25 ml) was stirred for 15 min, and then tetrahydropyranyl ether **1a**–**1i** (0.008 mol) was added. After the reaction was completed (2.0–5.0 h) as indicated by TLC, brine solution (20 ml) was introduced followed by saturated sodium hydrogen carbonate solution (20 ml). The reaction mixture was extracted with diethyl ether (3 × 20 ml). The combined organic extract was washed with water, dried over anhydrous Na_2SO_4, filtered, and evaporated to give the product (**2a**–**2i**).

RESULTS AND DISCUSSION

In the present study, Et_4NO_2 has been generated *in situ* by the phase transfer reaction of KO_2 and Et_4NBr in DMF at room temperature and subsequently allowed to react with a number of tetrahydropyranyl ethers (**1a**–**1i**). As an outcome, tetrahydropyranyl ethers (**1a–1i**) were readily deprotected to their corresponding carbonyl compounds (**2a**–**2i**).

The reactions were accomplished by using 2.0-fold molar excess of KO_2 with respect to substrate (**1**) in anhydrous DMF. Generally, the substrate tetrahydropyranyl ether was allowed to react with *in situ* generated superoxide ion for 2.0–5.0 h at room temperature. The reaction was then quenched with cold brine solution and work up to afford the product in excellent yield (Table 1). The total disappearance of the starting material was checked by thin-layer chromatography (TLC). All the oxidation products are known compounds and are identified by the comparison of their physical data and IR and NMR spectra with those of the authentic samples.

Table 1. Oxidative deprotection of tetrahydropyranyl (THP) ethers with *in situ* generated tetraethylammonium superoxide

Substrate **1**	Product **2**	Yield (%)
$Ph_2CHOTHP$ (**1a**)	Benzophenone (**2a**)	82
PhCH(Me)OTHP (**1b**)	Acetophenone (**2b**)	87
c-C_6H_{11}OTHP (**1c**)	Cyclohexanone (**2c**)	85
$PhCH_2OTHP$ (**1d**)	PhCHO (**2d**)	82
2-$MeOC_6H_4CH_2OTHP$ (**1e**)	2-$MeOC_6H_4CHO$ (**2e**)	80
3-$MeOC_6H_4CH_2OTHP$ (**1f**)	3-$MeOC_6H_4CHO$ (**2f**)	78
4-$MeOC_6H_4CH_2OTHP$ (**1g**)	4-$MeOC_6H_4CHO$ (**2g**)	78
2-$NO_2C_6H_4CH_2OTHP$ (**1h**)	2-$NO_2C_6H_4CHO$ (**2h**)	70
3-$NO_2C_6H_4CH_2OTHP$ (**1i**)	3-$NO_2C_6H_4CHO$ (**2i**)	75

CONCLUSIONS

In conclusion, tetraethylammonium superoxide represents a convenient reagent for one-pot oxidative deprotection of tetrahydropyranyl ethers to their corresponding carbonyl compounds.

REFERENCES

1. C. B. REESE: In: Protecting Groups in Organic Chemistry (Ed. J. F. W. McOmie), Plenum Press, London, 1973, Chapter 3.
2. L. F. FIESER, M. FIESER: Reagents for Organic Synthesis. John Wiley and Sons, New York, Vol. 1, 1967. 156 p.
3. T. W. GREENE, P. G. M. WUTS: Protective Groups in Organic Synthesis, John Wiley and Sons, New York, 2nd ed. 1991. 31 p.
4. G. SARTORI, R. BALLINI, F. BIGI, G. BOSICA, R. MAGGI, P. RIGHI: Protection (and Deprotection) of Functional Groups in Organic Synthesis by Heterogeneous Catalysis. Chem Rev, **104**, 199 (2004).
5. M. M. HERAVI, D. AJAMI, M. GHASSEMZADEH: Wet Alumina Supported Chromium (VI) Oxide: a Mild, Efficient and Inexpensive Reagent for Oxidative Deprotection of Trimethylsilyl and Tetrahydropyranyl Ethers in a Solventless System. Synthesis, **29**, 393 (1999).
6. E. J. PARISH, S. A. KIZITO, R. W. HEIDEPRIEM: A Novel Synthesis of Steroidal ^{4}, 3, 6-Diones Using Pyridinium Chlorochromate (PCC). Synth Commun, **23**, 223 (1993).
7. P. E. SONNET: Direct Conversion of Alcohol Tetrahydropyranyl Ethers to Aldehydes. Org Prep Proced Int, **10**, 91 (1978).
8. A. R. HAJIPOUR, S. E. MALLAKPOUR, I. M. BALTORK, H. BACKNEZHAD: An Easy and Fast Method for Oxidative Deprotection of Trimethylsilyl ethers, Tetrahydropyranyl ethers, and Ethylene acetals with $KMnO_4$ Supported on Alumina under Solvent-free Conditions. Synth Commun, **32**, 771 (2002).
9. M. NARENDER, M. S. REDDY, V. P. KUMAR, Y. V. D. NAGESWAR, K. R. RAO: Direct Systhesis of Carbonyl Compounds from THP Ethers with IBX in the Presence of β-Cyclodextrin in Water. Tetrahedron Lett, **46**, 1971 (2005).
10. M. RASOULI, M. A. ZOLFIGOL, M. H. MOSLEMIN, G. CHEHARDOLI: H_2O_2 as Green and Environmentally Benign Reagent for the Oxidation of TMS Ethers, THP ethers, and Alcohols in the presence of $\{[K.18\text{-Crown-}6]Br_3\}_n$. Green Chem Lett Rev, **10**, 117 (2017).

11. (a) R. S. RAGHUVANSHI: A Mild, Efficient and Fast Synthesis of Methyl N-Aryldithiocarbamates Using Superoxide Ion at Room Temperature. Phosphorus Sulfur Silicon, **190**, 133 (2015); (b) R. S. RAGHUVANSHI, V. P. YADAV, V. K. SINGH: Superoxide Ion Promoted Synthesis of 2-Arylbenzimidazoles from Schiff Bases. Lett Org Chem, **13**, 67 (2016); (c) S. PANDEY, A. K. SHUKLA, R. S. RAGHUVANSHI: A Mild Desilylation of Phenolic *tert*-Butyldimethylsilyl Ethers Using *in situ* Generated Tetraethylammonium Superoxide. Phosphorus Sulfur Silicon, **196**, 809 (2021); (d) R. S. Raghuvanshi, K. N. Singh: Mild and Efficient Method for Oxidative Deprotection of Trimethylsilyl Ethers Mediated by Tetraethylammonium Superoxide. Synth Commun, **37**, 1371 (2007); (e) B. YADAV, A. K. SHUKLA, R. S. RAGHUVANSHI: An Efficient, One-pot Synthesis of Organic Dithiocarbamates Using Tetraethylammonium Superoxide. Oxid Commun, **46**, 1030 (2023).
12. K. F. BERNADY, M. B. FLOYD, J. F. POLETTO, M. J. WEISS: Prostaglandins and Congeners. Synthesis of Prostaglandins via Conjugate Addition of Lithium trans-1-Alkenyltrialkylalanate Reagents. A Novel Reagent for Conjugate 1,4-Additions. J Org Chem, **44**, 1438 (1979).

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Green Synthesis of Gold Nanoparticles from Zingiber nigrum Leaves and their Efficacy in Photocatalytic Degradation of Toxic Dyes

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Abstract

The environmental friendliness of plants and their extracts makes them essential for the green manufacturing of nanoparticles. Plant extracts have been used to create a variety of metal nanoparticles. In this work, we report on an environmentally friendly approach of producing gold nanoparticles by utilizing aqueous extracts of Zingiber nigrum (ginger) leaves and assess their photocatalytic properties. The produced nanoparticles' capacity for photocatalysis and antioxidants was also evaluated. X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, and UV-Vis spectrophotometry were used to analyze the gold nanoparticles (Zn-AuNPs) that were synthesised by Zingiber nigrum. Powder XRD measurements verified the Zn-AuNPs' crystalline form. The Zn-AuNPs had an average particle size of 21.52 nm and were primarily spherical, according to micrographs obtained using high-resolution transmission electron microscopy (HRTEM). Polyphenolics and other functional groups that served as reducing and capping agents during the AuNP synthesis were discovered in the aqueous extract by FTIR spectral analysis. Significant antioxidant activity was demonstrated by these green-produced nanoparticles. The anthropogenic pollutant dyes methylene blue (MB) and rhodamine B (RhB) were catalyzed by Zn-AuNPs under UV radiation, with percent degradations of 93.25% and 97.64%, respectively. The photodegradation procedure adhered to a pseudo-first-order kinetic model. It has been suggested that the Zn on the Au nanoparticles effectively suppresses electron-hole recombination, which accounts for the observed photocatalytic activity of Zn-AuNPs. These findings support the notion that Zingiber nigrum is a viable bioresource for the production of gold nanoparticles with a wide range of environmental uses and is one of the novel features of this study.
Keywords: *Zingiber nigrum (ginger), Gold nanoparticles, Antioxidant, Photocatalysis.*

1. INTRODUCTION

Water is unquestionably a necessary resource for all facets of life, yet freshwater resources are currently scarce because of uneven distribution across nations and water contamination from industrial and agricultural processes [1]. The main contaminants that could be detected in the environment include inorganic pollutants including heavy metals, organic pollutants, and radioactive materials [2,3]. Toxic organic pollutants in particular are significant environmental contaminants that have posed a major risk to both human health and the ecosystem [4,5]. Combinations of several sources, including the widespread use of pesticides in agriculture, pharmaceuticals and the release of wastewater from industrial dye processes, lead to environmental organic pollution [6]. Methylene blue (MB), for example, is a recognised carcinogen with detrimental effects on both people and marine life [7]. Moreover, the extremely water-soluble organic cation dye rhodamine B dye (RhB) ($C_{28}H_{31}N_2O_3Cl$), a member of the xanthenes class, can cause irritation to the skin, eyes and lungs when in contact with humans [8]. In addition, it exhibits the chromophoric groups as well as a distinct carcinogenic and neurotoxic response. Since the textile dying is not a perfect process, at least 10% of the colour is lost to sewage washout. Thus, it is inevitable that these dyes will be removed or degraded quickly and effectively [9].

Unfortunately, organic debris, microbes, and hazardous compounds cannot be eliminated by the decades-old water treatment methods [10,11]. Because of nanomaterials' low cost, great efficacy in eliminating different types of contaminants, and reusability, researchers started looking for and relying on suitable alternatives in

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Adsorption Efficacy of Silver Nanoparticles Synthesized Using Wintergreen Plant Extract: A Green Approach to Dye Removal

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Abstract—This study uses wintergreen (*Gaultheria procumbens*) plant extract as a reducing agent in a green synthesis technique to create silver nanoparticles (AgNPs). Numerous analytical methods, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), UV-visible spectroscopy, and zeta potential analysis, were used to characterize the synthesized AgNPs. The results revealed the successful synthesis of AgNPs with an average size of approximately 25 nm and a face-centered cubic (FCC) crystalline structure. Furthermore, the synthesized AgNPs effectively removed direct yellow 4 (DY4) dye from aqueous solutions, displaying a maximum adsorption capacity of 92 mg/g. The adsorption kinetics of DY4 on AgNPs followed the pseudo-second-order model, indicating that chemisorption mechanisms predominantly govern the adsorption process. Additionally, the adsorption isotherms of DY4 on the surface of AgNPs adhered closely to the Langmuir isotherm model, suggesting monolayer adsorption on the uniform surface of AgNPs through strong adsorbate-adsorbent interactions. Moreover, the AgNPs demonstrated promising potential for reusability, as evidenced by the retention of approximately 97% adsorption efficiency even after undergoing four consecutive adsorption-desorption cycles. This highlights the robustness and durability of the AgNPs as effective adsorbents for wastewater treatment applications.

Keywords: adsorption, silver nanoparticles, plant extract, wintergreen plant, langmuir isotherm model, direct yellow 4

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INTRODUCTION

In recent years, the exploration of eco-friendly and sustainable solutions for various environmental and biomedical applications has gained significant momentum [1, 2]. Among these, the utilization of silver nanoparticles (AgNPs) derived from medicinal plant extracts has emerged as a promising avenue, offering dual benefits in terms of biological properties and wastewater dye removal [3, 4]. This introduction delineates the rationale behind exploring AgNPs synthesized from medicinal plant extracts, highlighting their potential as multifunctional agents for environmental remediation and biomedical applications [5–7]. The escalating concerns over environmental degradation and the deleterious effects of synthetic compounds on ecosystems and human health have underscored the urgency for eco-friendly and sustainable alternatives. Conventional methods for environmental remediation often involve the use of chemicals and processes that can exacerbate pollution and pose health risks [8, 9]. Hence, there is a pressing need to explore green and environmentally benign approaches for addressing pollution and improving environmental quality [10].

Conventional techniques for creating nanoparticles frequently call for dangerous chemicals and energy-intensive procedures, contributing to environmental degradation and posing risks to human health. Conversely, green nanotechnology focuses on building ecologically friendly methods for synthesizing nanoparticles from sustainable resources [11–13], such as plant extracts. By harnessing the phytochemicals present in medicinal plants, green synthesis provides a sustainable alternative to the basic principles of

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FIVE NEW RECORDS OF TUBULIFERAN THRIPS (THYSANOPTERA: PHLAEOTHRIPIDAE) FROM UTTARAKHAND, INDIA, WITH AN UPDATED CHECKLIST

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ABSTRACT

Five species of Phlaeothripidae (Thysanoptera: Tubulifera) have been recently recorded from Uttarakhand, India. These include *Androthrips ramachandrai* Karny, 1926; *Gynaikothrips uzeli* Zimmerman, 1900; *Haplothrips* (*Haplothrips*) *andresi* Priesner, 1931; *Haplothrips* (*Haplothrips*) *ganglbaueri* Schmutz, 1913; and *Haplothrips* (*Haplothrips*) *gowdeyi* (Franklin, 1908). An updated checklist of Tubuliferan thrips species recorded from Uttarakhand, including five new regional records is provided.

Key words: Tubulifera, Phlaeothripidae, Thysanoptera, thrips diversity, new records, Uttarakhand, *Androthrips*, *Gynaikothrips*, *Haplothrips*, insect taxonomy

Thrips, belonging to the order Thysanoptera, are economically significant insect pests. Globally, this order comprises 6,414 species in 787 genera, classified into two suborders: Terebrantia and Tubulifera (Tyagi et al., 2024). Of these, Tubulifera includes the largest and diverse family Phlaeothripidae, which contains approximately 3,809 extant species, divided into two subfamilies: Idolothripinae and Phlaeothripinae (ThripsWiki, accessed 20 June 2023). India is home to 816 thrips species across 265 genera, including 448 Tubulifera species under 143 genera, all within the family Phlaeothripidae (Tyagi and Kumar, 2016; Tyagi et al., 2024). The primary distinction between the two suborders is the morphology of the last abdominal segment and the presence or absence of a true ovipositor in females. In terebrantia, the last abdominal segment is typically conical or spherical, and female possess a well-developed, saw-like ovipositor. On the contrary, members of Tubulifera will have a tubular last abdominal segment, and females lack a true ovipositor.

Idolothripinae can be recognized from its sister group Phlaeothripinae by broad or sub-parallel maxillary stylets, the lack of maxillary guides, and long S2 setae on tergite IX, mainly feeding on fungal spores (Mound and Palmer, 1983). They feed on fungus and fungal hyphae (Mound and Tree, 2018). Uttarakhand, known for its abundant biodiversity and different agroclimatic zones, has so far reported 27 Tubuliferan species only (Ananthkrishnan and Sen, 1980; Tyagi and Kumar, 2016; Patidar et al. 2022; Tyagi et al. 2024). The recent study revealed the presence of five new species to the regional fauna. The new record of these species along with an updated checklist are provided.

MATERIALS AND METHODS

Thrips specimens from randomly selected host plants (5-10/ site) were collected by beating leaves and flowers onto an A4 size white paper or white tray by hand or with a stick (Bradley and Mayer, 1994). A comprehensive survey was conducted in 22 locations in the U.S. Nagar and Nainital districts of Uttarakhand. Thrips were collected in 1.5 ml Eppendorf tubes containing AGA solution (a mixture of 10 parts sixty per cent ethyl alcohol, 1-part glycerin, and 1-part acetic acid), using a fine wet camel hair brush. Vials were labelled with the date, host plant name, and location and kept at 4°C at the Molecular Entomology Laboratory, Department of Entomology, GBPUA&T, Pantnagar. The collected specimens were slide mounted and identified with the help available standard morphological keys (Mound, 1974; Ananthkrishnan and Sen, 1980; Eow et al., 2014). All the voucher specimens were deposited in the National Zoological Collection, Zoological Survey of India, Kolkata.

RESULTS AND DISCUSSION

Approximately 500 thrips specimens were collected, with five tubuliferan species representing three

genera viz: *Androthrips* Karny, 1911, *Gynaikothrips* Zimmermann, 1900 and *Haplothrips* Amyot and Serville, 1843 belonging to family Phlaeothripidae were identified as new distribution records for Uttarakhand. The detailed descriptions pertaining to them are presented in the full text, along with a systemic checklist of previously and newly recorded species. A comprehensive checklist of Tubuliferan thrips species recorded from the state of Uttarakhand is presented in Table 1. This list compiles data from previous faunistic surveys and recent field collections conducted during the present study. A total of 32 species belonging to multiple genera under the family Phlaeothripidae are documented, including five species newly reported from the region (*Androthrips ramachandrai*, *Gynaikothrips uzeli*, *Haplothrips (Haplothrips) andresi*, *H. ganglbaueri*, and *H. gowdeyi*). The checklist provides species-level information on their known distribution within Uttarakhand, associated host plants, and relevant literature sources. This

Table 1. Updated Checklist of Tubuliferan thrips of Uttarakhand

Sl. No.	Name of Species	Distribution	Host (s)	References
1.	*Aesthesiothrips jatrophae* Ananthakrishnan, 1961	Dehradun (Uttarakhand)	*Jatropha curcus* flowers	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
2.	*Androthrips ramachandrai* Karny, 1926	Pantnagar, U.S. Nagar (Uttarakhand)	Flowers of *Cascabela thevetia*	Present report*
3.	*Androthrips flavitibia* Moulton, 1933	Dehradun (Uttarakhand)	Galls of *Mallotus philippinensis*	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
4.	*Apelaunothrips bhowalii* (Ananthakrishnan, 1971)	Bhowali (Uttarakhand)	Dry sal leaves	Ananthkrishnan and Sen, 1980
5.	*Apterygothrips hispanicus* (Bagnall, 1916)	Kulhara, Garhwal (Uttarakhand)	*Rhododendron* flower	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
6.	*Azaleothrips bhattii* Vijay Veer & Chauhan, 1990	(Uttarakhand)	-	Tyagi et al., 2024
7.	*Bactrothrips idolomorphus* (Kamy, 1919)	Bhowali (Uttarakhand)	Dry & decaying leaves of wild tree & sal	Ananthkrishnan and Sen, 1980
8.	*Bactrothrips luteus* Ananthakrishnan, 1973	Bhowali (Uttarakhand)	Dry Sal leaves	Ananthkrishnan and Sen, 1980
9.	*Bamboosiella varia* (Ananthakrishnan and Jagadish, 1969)	Dehradun (Uttarakhand)	Palm sheaths; dry twigs	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
10.	*Dinothrips spinosus* (Schmutz, 1913)	Kumaon, Dehradun (Uttarakhand)	Log of *M. philippinensis*	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
11.	*Elaphrothrips insiginis* Ananthakrishnan, 1973	Almora (Uttarakhand)	Dry twigs	Ananthkrishnan and Sen, 1980
12.	*Elaphrothrips spiniceps* Bagnall, 1932	Kathgodam (Uttarakhand)	Dry twigs	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
13.	*Ethirothrips beesoni* (Moulton, 1928)	Dehradun (Uttarakhand)	Twigs of *Ficus religiosa*	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
14.	*Ethirothrips indicus* (Bagnall, 1921)	Dehradun (Uttarakhand)	Bark of half dead sal tree	Ananthkrishnan and Sen, 1980; Tyagi et al. 2024
15.	*Ethirothrips obscurus* (Schmutz 1913)	(Uttarakhand)	-	Tyagi et al., 2024
16.	*Gigantothrips gardneri* Ananthakrishnan, 1960	Mussoorie (Uttarakhand)	Leaves of an unidentified plant	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
17.	*Gigantothrips tibialis* (Bagnall 1921)	(Uttarakhand)	-	Tyagi et al., 2024

(contd.)

(contd. Table 1)

18.	*Gynaikothrips uzeli* Zimmerman, 1900	Pantnagar (Uttarakhand)	*Ficus benjamina*	Present report*
19.	*Hoplandrothrips corticis* Ananthakrishnan, 1972	Bhowali (Uttarakhand)	Dry Pine twigs	Ananthkrishnan and Sen, 1980
20.	*Haplothrips* (*Haplothrips*) *fungulus* Ananthakrishnan, 1973	Bhowali (Uttarakhand)	Decaying wood and twigs	Ananthkrishnan and Sen, 1980
21.	*Haplothrips* (*Haplothrips*) *reuteri* (Karny, 1907	(Uttarakhand)	-	Tyagi et al., 2024
22.	*Haplothrips* (*Haplothrips*) *andresi* Priesner, 1931	Pantnagar, U.S. Nagar (Uttarakhand)	*Momordica charatia*	Present report*
23.	*Haplothrips* (*Haplothrips*) *ganglbaueri* Schmutz, 1913	Haldwani (Uttarakhand)	*Sorghum bicolor*	Present report*
24.	*Haplothrips* (*Haplothrips*) *gowdeyi* (Franklin, 1908)	Pantnagar, U.S. Nagar (Uttarakhand)	*Citrus* sp.	Present report*
25.	*Holothrips fumidus* (Ananthakrishnan, 1972)	Mukteswar (Uttarakhand)	Dry twigs	Ananthkrishnan and Sen, 1980
26.	*Liothrips* (*Liothrips*) *bosei* Moulton, 1928	Dehradun (Uttarakhand)	Galls of *M. philippinensis*	Ananthkrishnan and Sen, 1980; Tyagi et al., 2024
27.	*Liothrips* (*Liothrips*) *sangali* Kulshrestha & Vijay Veer 1990	(Uttarakhand)	-	Tyagi et al., 2024
28.	*Mesothrips malloti* Moulton, 1929	Dehradun (Uttarakhand)	Galls of *M. philippinensis*	Tyagi et al., 2024
29.	*Malacothrips natalensis* (Trybom, 1912)	(Uttarakhand)	-	Tyagi et al., 2024
30.	*Psephenothrips uttarakhandensis* Patidar, Singha, Kumar & Tyagi, 2022	Nainital (Uttarakhand)	-	Patidar et al., 2022; Tyagi et al. 2024
31.	*Stephanothrips adnatus* Ananthakrishnan, 1972	Mukteswar (Uttarakhand)	Dry twigs	Ananthkrishnan and Sen, 1980
32.	*Urothrips tarai* (Stannard, 1970)	Nainital (Uttarakhand)	-	Ananthkrishnan and Sen, 1980

*New Record for Uttarakhand

updated inventory underscores the growing diversity of Tubuliferan thrips in the region and highlights the importance of continued faunistic exploration in under-sampled Himalayan ecosystems.

Systematic account - Order: Thysanoptera Haliday,1836; Suborder: Tubulifera Haliday, 1836; Family: Phlaeothripidae Uzel, 1895; Subfamily: Phlaeothripinae (Uzel) Priesner, 1928.

A. *Androthrips* Karny, 1911

The genus *Androthrips* includes 12 species of which 11 are from the tropics of Asia. So far, 5 species of this genus have been documented from India (Tyagi et al. 2024).

1. *Androthrips ramachandrai* Karny, 1926 (as shown in Fig. 1A)

Description: Both sexes with well-developed wings. Body and legs brown, but tarsi, as well as fore tibiae and apices of the mid and hind tibiae yellow. Antennal segment III yellow; IV-VI also yellow but with the apex variably brown. The forewings pale. Head longer than wide. Postocular setae long with a weakly capitate apex. Maxillary stylets retracted to the postocular setae and about one-third of the width of the head. Antennae 8-segmented, with segment III with 3 sensoria and segment IV bearing four. No sculpture in the pronotum, but bears four pairs of major setae; minute anteromarginal setae. Paired prosternal basantra, along with a distinct transverse mesopresternum. Fore femur

frequently larger and with a rounded tubercle on the inner margin near the base. The foretarsal tooth notably enormous. Metanotum with weak linear reticulation. Forewing weakly constricted medially and with around 12 duplicate cilia. Pelta elongate triangular. Abdominal tergites II-VII each include two pairs of sigmoid wing-retaining setae. On tergite IX, setae S1 nearly as long as the tube. Males smaller than females and possess short and thick S2 setae on tergite IX (Ananthakrishnan, 1971; Mound & Ng, 2009; Mound and Kibby, 1998).

Material examined: 2♀: India, Uttarakhand, Pantnagar, G.B. Pant University of Agriculture and Technology, Pantnagar, 243.84 MSL, 07.xii.2021, *Cascabela thevetia*, collected by S. Saran.

Distribution: India: Assam, Arunachal Pradesh, Tamil Nadu, Kerala and Uttarakhand (Present record); **World:** Japan, Southern USA, Mexico, Puerto Rico, Costa Rica, Colombia, Argentina, Brazil, Syria and western Asia (Ananthkrishnan and Sen, 1980; Ali, 2015; Tyagi and Kumar, 2016; Tyagi et al. 2024).

B. *Gynaikothrips* Zimmermann, 1900

This genus comprises 40 species and all of them are gall inducers and produce leaf-galls or leaf-rolls. The majority of these species occur in the Oriental region especially on the tropical or subtropical plants, although two related pest species, *Gynaikothrips ficorum* and *G. uzeli*, are extensively distributed due to horticultural trade with ornamental plant *Ficus* spp. (Fig. 2) (Mound and Kibby, 1998). This genus includes 11 species recovered from various states of India (Tyagi et al., 2024).

1. *Gynaikothrips uzeli* Zimmerman, 1900 (Fig. 1B)

Description: Both sexes possess wings. Body dark brown, with yellow tarsi and tibial apices. Antennal segments II-V yellow; segment VI shaded at the apex, VII shaded in the distal half, and VIII uniformly light brown. Forewings pale with shaded margins on the distal half. Antennae 8-segmented, with segment III with a single sense cone and segment IV with three sense cones. Head longer than wide and slightly constricted behind the compound eyes. First ocellus raised on a small prominence over the antennal bases. Postocular setae with bluntly pointed, arising well behind compound eyes, but barely reaching to the posterior margin of the eyes. Maxillary stylets retracted almost to the level of postocular setae and about one-third of the width of the head. Pronotum with conspicuous transverse lines of sculpturing, often forming swirling patterns. Major setae variable in size; anteromarginals minute; anteroangulars usually well developed; posteroangulars at least 0.7 times as long as the epimeral setae and consistently longer than the discal setae. Epimeral sutures vary in completeness. Prosternal basantra absent, and mesopraesternum boat-shaped. Metathoracic sternopleural sutures absent. The metanotum highly sculptured with longitudinal reticulations. Fore tarsus with a small or poorly developed tooth. Forewing parallel-sided and with approximately 15 duplicated cilia. Pelta broadly triangular with distinct median reticulations and internal markings. Abdominal tergites II-VII each with two pairs of sigmoid wing-retaining setae. On tergite IX, setae S1 sharply pointed and about 0.8 times the length of the tube. Tube longer than head. Males smaller than females. They lack the fore tarsal teeth, and S2 setae on tergite IX, short and stout. Sternite VIII lacks glandular areas (Mound and Tree, 2016; Mound and Ng,

Fig. 1. Morphological features of three tubuliferan thrips species recorded from Uttarakhand: (A) *Androthrips ramachandrai* (female, dorsal view), (B) *Gynaikothrips uzeli* (female, dorsal view), (C) *Haplothrips (Haplothrips) gowdeyi* (female, dorsal view).

Fig. 2. Leaf galls caused by *Gynaikothrips uzeli* on *Ficus* spp. in Uttarakhand: (A) Infested *Ficus* plant showing multiple leaf galls, (B) Leaf manually opened to reveal numerous thrips inside the gall chamber, (C) Single leaf gall showing characteristic curling and thickening of the lamina

2009; Ananthakrishnan, 1971). Leaf galls induced by *Gynaikothrips uzeli* on *Ficus* spp. (Fig. 2A-C).

Material examined: 4♀: India, Uttarakhand, Pantnagar, G.B. Pant University of Agriculture and Technology, Pantnagar, 243.84 MSL, 13.xii.2021, *Ficus benjamina*, collected by S. Saran.

Distribution: India: Assam, Karnataka, Odisha, Tamil Nadu, West Bengal and Uttarakhand (Present record); **World:** Java, Indonesia/ Malaysia, Australia, New Caledonia, Timor Leste, Philippines, Singapore, Taiwan, Vietnam, Laos, Cambodia, Thailand, Malaysia, Indonesia, Maldives Islands, Spain, Syria, Israel, Costa Rica, Columbia, Peru, Brazil, Galapagos Islands, USA (Florida, South Carolina) (Tyagi and Kumar, 2016; Johnson and Varatharajan, 2018; Mound and Tree, 2021; Tyagi et al. 2024).

2. *Gynaikothrips* sp. (Fig. 2)

This unidentified species was also collected from *Ficus benjamina*. However, identification proved challenging; based on diagnostic features, it may represent *G. ficorum* (Marchal), but confirmation requires further analysis.

C. *Haplothrips* Amyot and Serville, 1843

It is the largest genus in this group, with 240 species divided into two subgenera: *Haplothrips* and *Trybomiella*, which are listed internationally (Mound and Hastenpflug-Vesmanis, 2021). *Haplothrips* has duplicate cilia on its forewings, whereas *Trybomiella* does not. In India, however, only 25 *Haplothrips* species have been described, 16 of which belong to the subgenus *Haplothrips* and 9 to *Trybomiella* (Tyagi and Kumar, 2016; Tyagi et al. 2024) *Haplothrips* species breed in flowers and can be found in several plant genera of Asteraceae and Poaceae. Some *Haplothripini* species are predators, whereas a few may be mycophagous (Mound and Matsunaga, 2017).

1. *Haplothrips* (*Haplothrips*) *andresi* Priesner, 1931

Description: Body and legs uniformly dark brown to black. Fore tibiae yellow toward the apex with outer margins dark; mid and hind tibiae also dark with distal apices pale yellow. All tarsi pale yellow. Antennal segment II slightly paler at the apex, III entirely yellow, and segments IV-VI yellow in the basal two-thirds. Major setae on the head, thorax, and base of forewings, dark. Head somewhat longer than broad, with well-developed postocular setae that slightly shorter than the compound eyes and blunt or capitate. Maxillary stylets 0.26-0.31 times the width of head width apart and retracted to the postocular setae. Antennae 8-segmented, with segment III with a single sensorium. Pronotum with five pairs of major setae, and antero-marginals well developed. Mesopresternum boat-shaped. Fore tarsus lacks teeth in females, while in males it bears a tiny tooth. Forewing with 10-12 duplicated cilia. Subbasal setae S1 and S2 capitate, while S3 pointed. Pelta triangular. Abdominal tergite IX indicates setae S1, S2, and S3; tube short. In general morphology males similar to females but smaller in size and possess smaller fore tarsi with a tiny tooth.

Material examined: 2♀: India, Uttarakhand, Pantnagar, Vegetable Research Centre, Pantnagar, 243.84 MSL, 02.x.2022, *Momordica charantia*, collection by S. Saran.

Distribution: India: Tamil Nadu, Arunachal Pradesh, Manipur and Uttarakhand (Present record); **World:** Egypt, N. Africa, Sinai, Palestine, Iran (Minaei and Mound, 2008; Tyagi and Kumar, 2016; Tyagi et al., 2024).

2. *Haplothrips* (*Haplothrips*) *ganglbaueri* Schmutz, 1913

Description: Antennae 8-segmented, with segment III characteristically asymmetrical with a single sense cone, and segment IV with four well-defined sense cones. Notopleural sutures complete, a common feature of many *Haplothrips* spp. Prothorax possess well developed dorsal setae, all of which expanded apically, contributing to its distinct chaetotaxy. Forewings slender with 4-7 duplicated cilia, critical for identification. Abdominal tergites III-VII each with two pairs of sigmoid wing retaining setae, a typical feature of *Haplothrips* species with a flower-associated existence (Bhatti, 1990; Mound and Minaei, 2007; Ananthakrishnan, 1971).

Material examined: 3♀: India, Uttarakhand, Nainital, Kunwarpur, Haldwani, 443 MSL, 15.ix.2021, *Sorghum bicolor*, collected by S. Saran.

Distribution: India: Andaman Island, Andhra Pradesh, Arunachal Pradesh, Assam, Delhi, Haryana, Karnataka, Madhya Pradesh, Manipur, Meghalaya, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal and Uttarakhand (Present record); **World:** Widespread across the Oriental region, from Iran to Japan. (Ananthkrishnan and Sen, 1980k; Minaei and Mound, 2008; Singh and Rachana, 2020; Tyagi et al., 2024).

3. *Haplothrips* (*Haplothrips*) *gowdeyi* (Franklin, 1908) (Fig. 1C)

Description: This species is commonly referred to as the gold-tipped tubular thrips. Body dark brown; Antennal segments III-VI pale yellow. Antennal segment III with two sense cones, while IV with four that contrasts with the dark brown body. Forewing pale with base shaded, and major setae throughout the body dark brown, with the exception of tergite IX. Head slightly longer than wide, and postocular setae weakly capitate and about as long as the width of the compound eyes, emerging near to the posterior margin of the eye. Maxillary stylets retracted to the postocular setae, approximately half the head width apart, with a noticeable maxillary bridge present. Pronotum with five pairs of slender, capitate major setae. Basantra well developed; mesopresternum complete and boat-shaped, but narrow medially. Metathoracic sternopleural sutures absent. Fore tarsus bears a tiny tooth near the apex. Forewings constricted medially, with approximately 8 duplicated cilia. All three sub-basal setae capitate. Pelta triangular in shape. Abdominal tergites II-VII each carry two pairs of sigmoid wing-retaining setae. Tergite IX with sharp, slender S1 setae nearly as long as the tube. Tube shorter than the head width. This species has been frequently recorded to breed in inflorescences of grass and other flowers, including Asteraceae (Ananthakrishnan, 1971; Bhatti, 1990; Mound and Wells, 2015).

Material examined: 5♀: India, Uttarakhand, Pantnagar, Horticulture Research Centre, Pantnagar, 244 MSL, 12.ii.2021, *Citrus* sp., collected by S. Saran.

Distribution: India: Andaman Island, Arunachal Pradesh, Assam, Meghalaya, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal and Uttarakhand (Present record); **World:** It is extensively distributed around the world in tropical and subtropical countries. (Tyagi and Kumar, 2016; Tyagi et al. 2024).

The present study increases the known Tubuliferan fauna in Uttarakhand, increasing the known species count from 27 to 32. These new records include *A. ramachandrai*, *G. uzeli*, *H. (H.) andresi*, *H. (H.) ganglbaueri*, and *H (H.) gowdeyi*. Notably, two genera viz., *Androthrips* and *Gynaikothrips* are newly recorded from the region for the first time, indicating the underexplored diversity of Phlaeothripidae in Uttarakhand. These findings emphasize the potential influence of host plant diversity, habitat heterogeneity, and agroecological dissimilarity in shaping the local thrips assemblages. For example, *G. uzeli* and *A. ramachandrai*, known to be widely distributed in tropical and subtropical areas, were recovered from ornamental and flowering hosts such as *Ficus benjamina* and *Cascabela thevetia*, correspondingly- plants that are increasingly common in urban and peri-urban environments. The finding of *Haplothrips* species on both field (e.g., *Sorghum bicolor*, *Momordica charantia*) and horticultural crops (*Citrus* sp.) also specifies their ecological plasticity and impending roles as both florivores and facultative predators.

Previous works (Ananthakrishnan and Sen, 1980; Tyagi and Kumar, 2016; Tyagi et al. 2024) have emphasized the limited faunistic studies of thrips from Uttarakhand. The present records provide empirical support to the idea that the Tubuliferan thrips of this

region are still poorly known and may harbour further undescribed or unrecorded taxa. This is particularly relevant considering the state's unique geographical location at the interface of the Himalayan and Indo-Gangetic plains, which bring up ecological transitions and species turnover. Likewise, the unearthing of a potentially unidentified *Gynaikothrips* species points to the necessity for further integrative systemic studies employing molecular and morphometric analyses. Such approaches would be critical in resolving cryptic species complexes, chiefly within genera such as *Gynaikothrips*, known for their close morphological affinities and broad intraspecific inconsistency.

The updated checklist presented here provides a foundation for forthcoming ecological and biogeographical studies of thrips in the region. Regular surveys across diverse seasons, altitudes, and cropping systems are recommended to monitor population dynamics, track invasive species, and assess role of thrips in phytophagy, pollination, or fungivory. The documentation of these taxa also grasps importance for insect pest management strategies, mostly in the context of climate-induced shifts in insect distribution.

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AUTHOR CONTRIBUTION STATEMENT

S S, R M and K S jointly conceptualized the study and contributed to the preparation of the original draft. R.M. provided supervision throughout the research process. All authors critically reviewed and approved the final version of the manuscript.

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CONFLICT OF INTEREST

No conflict of interest.

REFERENCES

Ali A Y. 2015. First record in Syria of Androthrips ramachandrai Karny, 1926 (Thysanoptera: Phlaeothripidae). Applied Entomology and Zoology 61(3): 291-293.

Ananthakrishnan T N. 1971. Taxonomy of Indian Thysanoptera. Zoological Monograph No. 1. Zoological Survey of India, Kolkata. 276 pp.

Ananthakrishnan T N, Sen S. 1980. Taxonomy of Indian Thysanoptera. pp. 146-171. In: Handbook Series No. 1. Zoological Survey of India, Kolkata.

Bhatti J S. 1990. Catalogue of Thysanoptera of the Indian Subcontinent. Zoological Survey of India, Calcutta. 409 pp.

Bradley S J, Mayer D F. 1994. Evaluation of monitoring methods for western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), during the blossom period of 'Granny Smith' apples. Journal of the Entomological Society of British Columbia 91: 63-68.

Eow L X, Mound L A, Tree D J, Cameron S L. 2014. Australian species of spore feeding Thysanoptera in the genera *Carientothrips* and *Nesothrips* (Thysanoptera: Idolothripinae). Zootaxa 3821(2): 193-221.

Johnson T, Varatharajan R. 2018. Thrips (Insecta: Thysanoptera) fauna from the Dampa Tiger Reserve, Mizoram, India. Halteres 9: 143-150.

Minaei K, Mound L A. 2008. The Thysanoptera Haplothripini (Insecta: Phlaeothripidae) of Iran. Journal of Natural History 42(41-42): 2617-2658.

Mound L, Palmer J M. 1983. Spore feeding Thysanoptera of the genus *Anactinothrips* with a new subsocial species from Panama. Journal of Natural History 17(5): 789-797.

Mound L A. 1974. Spore feeding thrips (Phlaeothripidae) from leaf litter and dead wood in Australia. Australian Journal of Zoology Supplementary Series 22(27): 1-106.

Mound L A, Hastenpflug Vesmanis A. 2021. All genera of the world: Order Thysanoptera (Animalia: Arthropoda: Insecta). Megataxa 6(1): 2-69.

Mound L A, Kibby G. 1998. Thysanoptera: An identification guide, 2nd edn. CAB International, Wallingford. 70 pp.

Mound L A, Matsunaga J N. 2017. The species of *Haplothrips* (Thysanoptera: Phlaeothripinae) and related genera recorded from the Hawaiian Islands. ZooKeys 662: 79-91.

Mound L A, Minaei K. 2007. Australian species of the genus *Haplothrips* (Thysanoptera: Phlaeothripidae) associated with flowers. Australian Journal of Entomology 46(3): 233-240.

Mound L A, Ng Y F. 2009. An illustrated key to the thripine genera of Asia (Thysanoptera: Thripidae). Zootaxa 2265: 1-40.

Mound L A, Tree D J. 2016. Identification and host associations of *Gynaikothrips* species (Thysanoptera: Phlaeothripinae) damaging leaves of Ficus trees in Asia and the Americas. Zootaxa 4174(1): 91-101.

Mound L A, Tree D J. 2018. Asia–Australia distribution patterns among species of *Mystrothrips* (Thysanoptera: Phlaeothripinae), with two new species. Zootaxa 4526(3): 347-357.

Mound L A, Tree D J. 2021. Taxonomic problems with *Gynaikothrips* and

related genera (Thysanoptera: Phlaeothripinae): The *ficorum*/*uzeli* complex and taxa endemic to Australia. Zootaxa 5023(4): 537-554.

Mound L A, Wells A. 2015. Endemics and adventives: Thysanoptera (Insecta) biodiversity of Norfolk, a tiny Pacific island. Zootaxa 3964(2): 183-210.

Patidar A, Singha D, Kumar V, Tyagi K. 2022. A new species of *Psephenothrips* (Thysanoptera: Phlaeothripidae) with one new record from India. Zootaxa 5159(3): 440-444.

Singh S, Rachana R R. 2020. Diversity and population dynamics of thrips species on horticultural crops in Punjab. Indian Journal of Horticulture 77(4): 647-654.

ThripsWiki. 2023. Thrips information database. http://thrips.info/wiki/ (Accessed on 20 June 2023).

Tyagi K, Kumar V. 2016. Thrips (Insecta: Thysanoptera) of India: An updated checklist. Halteres 7: 64-98.

Tyagi K, Patidar A, Singha D, Kumar V. 2024. Fauna of India Checklist: Arthropoda: Insecta: Thysanoptera, Version 1.0. Zoological Survey of India.

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Physico-chemical Quality Comparison of Fortified Yoghurt with Strawberry Fruit Juice

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ABSTRACT

Background: Today, India is the world's largest and fastest growing market for milk and milk products. Yoghurt (also spelled "yogurt" or "yoghourt") has been a part of the human diet for several millennia and goes by many names throughout the world. Yoghurt is a coagulated milk product obtained by specific lactic acid fermentation, through the action of *L. bulgaricus* and *S. thermophilus*. In recent years, yoghurt has become a popular carrier for incorporating the probiotic species, *L. acidophilus* and *B. bifidium*. The carbohydrate content of yoghurt is easily absorbed by even lactose maldigestors which makes it a valuable adjunct to any healthy diet. Presence of α-D-galactosidase activity in pro-biotic yoghurt indicates its suitability for lactose-intolerant infants. Yoghurt is considered by most regulatory agencies worldwide to be a fermented milk product that provides digested lactose and specifically defined, viable bacterial strains, typically *Streptococcus thermophilus* and *Lactobacillus bulgaricus*.

Methods: The experiment was conducted in the laboratory of the Department of Animal Husbandry and Dairying, at Udai Pratap (Autonomous) College, in Varanasi. The Plain and Strawberry flavoured Yoghurt samples were tested and statistically analyzed. The experimental techniques employed during the course of present investigation were done under various stages.

Result: Physical properties of yoghurt are mainly influenced by milk composition and the manufacturing conditions under which it is prepared. Further, variables affecting the physical properties are the heat treatment applied to milk, the protein content, acidity, culture, additives, homogenization, mechanical handling of coagulum and presence of the stabilizers.

Key words: Fermentation, Milk, Probiotics, Strawberry, Yoghurt.

INTRODUCTION

Dairy is the largest agriculture commodity in India, contributing 5% to the national economy and employing over 8 crore farmers directly. According to Food and Agriculture Organization Corporate Statistical Database's (FAOSTAT) production data, India ranks first in milk production, accounting 24% of global milk production in the year 2021-22. Milk production has increased by 51.05% in the past eight years reaching 221.06 million tons in 2021-22 (FAO, 2023). Milk production is growing at the annual growth rate of 6.1% over the past 8 years whereas world milk production is growing at 1.2% per annum. Per capita milk availability in India is 444 grams per day, surpassing the world average of 394 grams per day.

Yoghurt (also "yogurt" or "yoghourt") is an ancient food that has known by many names over the millennia: katyk (Armenia), dahi (India), zabadi (Egypt), mast (Iran), leben raib (Saudi Arabia), laban (Iraq and Lebanon), roba (Sudan), iogurte (Brazil), cuajada (Spain), coalhada (Portugal), dovga (Azerbaijan) and matsoni (Georgia, Russia and Japan) (Fisberg and Machado, 2015). The word "yoghurt" is believed to have come from the Turkish word "yoğurmak" which means to thicken. It is believed that milk products were incorporated into the human diet around 10000-5000 BC, with the domestication of milk producing animals (Shree *et al.,* 2017). However, milk spoiled easily, making it difficult to use. At that time, herdsmen in the Middle East carried milk in bags made of intestinal gut. It was discovered that contact with intestinal juices caused the milk to curdle and sour, preserving it and allowing for conservation of a dairy product for extended periods of time (Shree *et al.,* 2017). Indian Ayurvedic scripts, dating from about 6000 BC, refer to the health benefits of consuming fermented milk products (Fisberg and Machado, 2015). Today, there are more than 700 yogurt and cheese products found in Indian cuisine (Kaur *et al.* 2017). For millennia, making yogurt was the only known safe method for preserving milk, other than drying it. Yogurt was well known in the Greek and Roman empires and the Greeks were the first to mention it in written references in 100 BC, noting the use of yogurt by barbarous nations. In the Bible (Book of Job),

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Abraham owed his longevity and fecundity to yogurt consumption and there is reference to the "Land of Milk and Honey," which many historians have interpreted to be a reference to yogurt (Fisberg and Machado, 2015). Yoghurt is more nutritious than milk (Banerjee *et al.,* 2017; Govindammal *et al.,* 2017). Even lactose-intolerant individuals can also consume yoghurt because lactose is converted to glucose and galactose before being fermented to produce lactic acid (Felix *et al.,* 2022).

Strawberry, *Fragaria ananassa* Duch., a member of family Rosaceae (Dwivedi *et al.,* 2024), is a well-known non-climacteric fruit that has lot of nutritional and organoleptic characteristics that are commercially acceptable, therefore it grown to eat as fresh, processed, preserved (Muttulani and Turnos, 2025). Strawberry fruit contains high content of flavonoids, epicatechin, catechin, proanthocyanidin B1 and flavonols (Dwivedi *et al.,* 2024; Muttulani and Turnos, 2025).

From the ancient time, fermented milk products were considered as health benefiting food (Shiby and Mishra, 2013; Govindammal *et al.,* 2017). It was used for treating diarrhea and intestinal disorders. Yoghurt consumption leads to decrease in pH of stomach, which can result in reduction of pathogen transit and also it improves the gut microflora and metabolic activity. Yoghurt can also be used to supplement the diet with heart-healthy nutrients. The microbial balance in the gut is critical to prevent gastrointestinal disorders. It also aids in the control of diabetes by increasing insulin sensitivity. Novel flavonol in the strawberry fruit plays an important role in anticancer and antioxidant activity (Muttulani and Turnos, 2025).

Physical properties of yoghurt are mainly influenced by milk composition and the manufacturing conditions under which it is prepared. Further, variables affecting the physical properties are the heat treatment applied to milk, the protein content, acidity, culture, additives, homogenization, mechanical handling of coagulum and presence of the stabilizers (Rasic and Kurman, 1978; Parnell *et al.,* 1986).

The objectives of the present study are, 1. To assess the physical qualities of milk samples. 2. To study the chemical qualities of milk samples. 3. To analyze the physicochemical quality of strawberry yoghurt prepared from addition of different concentration levels of strawberry juice.

MATERIALS AND METHODS

The experiment was conducted during January, 2023 to December, 2024, in the departmental laboratory of the Department of Animal Husbandry and Dairying, at Udai Pratap (Autonomous) College, Varanasi, Uttar Pradesh, India. The Plain and Strawberry flavoured Yoghurt samples were tested and statistically analyzed. The experimental techniques employed during the course of present investigation were done under various stages such as, Material required for preparation of plain and strawberry flavoured yoghurt, procurement of ingredients, Procedure adopted for preparation of Plain and Strawberry flavoured Yoghurt, Testing of experimental product, Chemical analysis of Plain and Strawberry flavoured yoghurt, Organoleptic quality of Plain and Strawberry flavoured yoghurt, Statistical analysis of Plain and strawberry flavoured yoghurt.

Preparation of fruit juice

Fruits were washed with clean water and chopping strawberry with the help of a knife aseptically. The seeds were removed from the strawberry and also the black spots were removed. Strawberries were blended and the juice was filtered with a clean cloth/sieve. Fruits juice was obtained from the crushed fruit and addition of desirable sugar concentration according to experimental design. Then boiling the mixture for 2 min at 90°C and filled into sterile glass jars.

Treatment combinations

The different treatment combinations used in experiment are as follows:

T_0- Yoghurt mix with 12% sugar and inoculated with 2.0% yoghurt culture. It is Control setup, *i.e.* without addition of strawberry juice.

T_1- Yoghurt mix with 12% sugar and inoculated with 2.0% yoghurt culture. The strawberry fruit pulp/juice was added at 5 per cent.

T_2- Yoghurt mix with 12% sugar and inoculated with 2.0% yoghurt culture. The strawberry fruit pulp/juice was added at 10 per cent.

T_3- Yoghurt mix with 12% sugar and inoculated with 2.0% yoghurt culture. The strawberry fruit pulp/juice was added at 15 per cent.

T_4- Yoghurt mix with 12% sugar and inoculated with 2.0% yoghurt culture. The strawberry fruit pulp/juice was added at 20 per cent.

The mix was then sent for incubation at 42°C until the complete curd formation/coagulation of yoghurt (8-10hrs). After that yoghurt was filled in the cups and sent for storage at about 4°C under refrigeration. Thus, the yoghurt was ready (Fig 1 and Fig 2).

A group of trained tasters (the panel) evaluates samples for organoleptic properties-like visual colour, texture, flavour and tastes for collected milk samples and strawberry yoghurt samples through nine point's hedonic rating scale (Table 1 and Table 4).

Statistical analysis

All the data obtained were statistically analyzed for its validity by using Completely randomized design and critical difference (C.D) technique. The statistical analysis plan includes total number of treatments 05, total number of errors 25 and total number of trails 30.

RESULTS AND DISCUSSION

The quality of yoghurt is greatly dependent on the type and quality of raw material used for its manufacturing. The compositional parameters, like fat content mainly control

the body and texture characteristics and flavour of the product. The research investigation is described separately in physical and chemical parameters. Results obtained during the course of this study have been summarized in the following tables after subjecting to statistical analysis wherever necessary. The findings have been also illustrated diagrammatically. A brief description of finding is also discussed with each table.

Physical qualities of milk

The five cow milk samples (S_1, S_2, S_3, S_4 and S_5) were taken and the observations were taken just after the collection of the samples with regard to physical properties of milk on the basis of colour, flavour and taste by panel of testers using nine point's hedonic rating scale (Table 1).

Colour: The cow milk samples showed light yellowish colour which was same for remaining all samples of milk.

Flavour: It indicates that all milk samples were obtained from dairy farm and local market were normal flavour and they were free from any off flavour.

Taste: The cow milk taste was to be found slightly sweet.

Chemical qualities of milk

In Table 2, some important nutritional constituents were analyzed separately for five different milk samples (S_1, S_2, S_3, S_4 and S_5) of cow to identify their chemical qualities, acidity, fat, protein and lactose. The data indicate that the acidity percentage of cow milk samples varied between 0.15 to 0.17 with an average of 0.158. The fat and protein

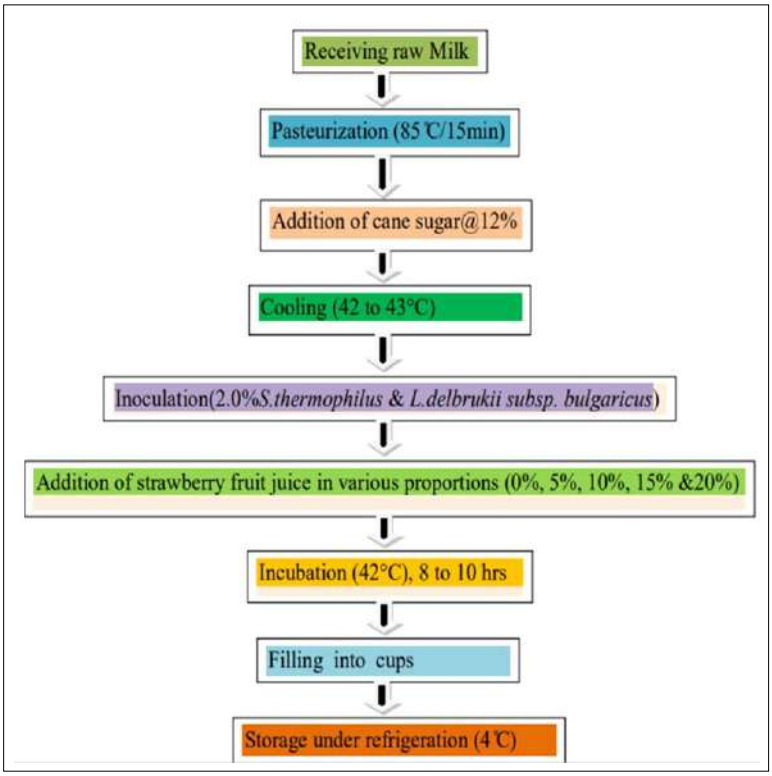

Fig 1: Flow diagram for making experimental strawberry flavoured yoghurt.

Fig 2: Strawberry flavoured yoghurt.

content of milk samples lies between 3.91 to 4.54 and 3.33 to 4.93 with an average of 4.306 and 3.866 whereas the lactose content of milk samples lies between 3.23 to 5.05 with an average of 4.302.

The null hypothesis (H_0) is rejected and the alternative hypothesis is taken because 78.881>3.239, (FC>FT).This means that the statistically analysis (Table 3) shows that there is a significant difference between the acidity, fat, protein and lactose content in milk samples.

Physical quality of yoghurt

The physical qualities, *viz.*, colour, flavour, body and texture of yoghurt samples were studied and the relevant data are presented in Table 4, the yoghurt obtained from the five different samples of cow milk with treatments (T_0, T_1, T_2, T_3 and T_4) they were different colours, flavour, body and texture due to addition of strawberry juice/pulp at different (0%, 5%, 10%, 15% and 20%) levels.

i) Colour

Colour is an important sensory parameter besides taste, aroma and texture. Colour is one of the factors that influence consumer acceptance of food products. Control yoghurt (T_0) is yoghurt without addition of any ingredients including sweeteners or other flavours. In this study, the control yoghurt produced was white whereas the yoghurt with addition of strawberry juice/pulp has a light pink colour that comes from the anthocyanin content in strawberries. The higher the concentration of strawberry juice/pulp added resulted in the lighter colour of the yoghurt (Jaster *et al.,* 2018).

ii) Body and texture

Yoghurt texture determines the quality of the resulting yoghurt. Generally, good yoghurt has a soft texture like porridge, not too runny and not too thick (Faisal *et al.,* 2019). The texture of the yoghurt produced in this study was soft and smooth at various levels. The addition of strawberry juice/pulp causes yoghurt texture becomes thicker.

iii) Flavour and taste

The taste of the strawberry yoghurt and the control yoghurt were sour in taste due to the fermentation takes place, by lactic acid bacteria that converts fructose, sucrose and galactose into lactic acid.

Chemical quality of yoghurt

The yoghurt samples were analyse on the basis of organoleptic and chemical tests. The physical qualities, *viz.*, colour, flavour, body and texture of yoghurt samples were studied. The result found that the yoghurt obtained from the five different samples of cow milk with treatments (T_0, T_1, T_2, T_3 and T_4) they were different colours, flavour, body and texture due to addition of strawberry juice/pulp at different (0%, 5%, 10%,15% and 20%) levels .In this study, the control yoghurt produced was white whereas the yoghurt with addition of strawberry juice /pulp has a light pink colour that comes from the anthocyanin content in strawberries. The higher the concentration of strawberry juice/pulp added resulted in the lighter colour of the yoghurt. The texture of the yoghurt produced was soft and smooth at various levels and the addition of strawberry juice/pulp causes yoghurt texture becomes thicker. The taste of the strawberry yoghurt and the control yoghurt were sour in taste.

In comparing chemical analysis, it was observed that moisture content and acidity were increased in prepared yoghurt with strawberry juice incorporation because strawberry juice contains higher moisture content (71.96%) and acidity (1.02) which decreases the shelf life of the yoghurt. It was observed that P(0% or plain yoghurt) contains lower moisture content (71.80%) and other samples of 5%, 10%, 15% and 20% contains 71.84%,

Table 1: Physical qualities of milk samples.

Type of milk	Colour	Flavour	Taste
Cow milk	Light yellowish	Pleasant	Slightly sweet

Table 2: Average mean values of chemical properties of five different milk samples of cow.

Samples*	Type of milk	Constituents	Mean (%)	Range (%)
05		Acidity	0.158	0.15 - 0.17
(S_1, S_2, S_3, S_4 and S_5)	Cow milk	Fat	4.306	3.91 - 4.54
		Protein	3.866	3.33 - 4.93
		Lactose	4.302	3.23 - 5.05

*****mean values, n=3.

Table 3: Analysis of Variance (ANOVA) for the acidity, fat, protein and lactose content in five different samples of cow milk (S_1, S_2, S_3, S_4 and S_5).

Sources of variation	Degrees of freedom	Sum of squares	M.S. (variance)	F Cal.	F. value at 5%
Between the groups	3	60.6395	20.2132	78.8807	3.239
Within the groups (error)	16	4.1	0.2563		
Total	19	64.7395			

71.86%, 71.94% and 71.96% respectively. It was also observed that P (0% or plain yoghurt) contains lower acidity content (0.8%) and the other samples of 5%, 10%, 15% and 20% contains 0.9%, 0.9% 1.00% and 1.02%. On the other hand , ash and fat content were decreased with the addition of strawberry juice because strawberry juice contains low ash (0.69%) and fat (4.01%) content. It was observed that P (0% or plain yoghurt) contains higher fat content (4.73%) and other samples of 5%, 10%, 15% and 20% contains 4.36%, 4.12%, 4.08% and 4.01% respectively. It was also observed by chemical composition analysis that P (0% or plain yoghurt) contains higher ash content (0.79%) and other samples of 5%, 10%, 15% and 20% contains 0.76%, 0.73%, 0.70% and 0.69% respectively. The protein content of P (0% or plain yoghurt) were decreased about (3.87%) and other samples of 5%, 10%, 15% and 20% contains higher protein content such as 4.15%, 4.24%, 4.34% and 4.41% respectively. Thus, total solids content increases as P (0% or plain yoghurt) contains (28.22%) and other samples of 5%, 10%, 15% and 20% contains 28.18%, 28.16%, 28.08% and 28.00% respectively.

Average of different physicochemical properties of the control and strawberry fruit juice/pulp yoghurt

The highest mean value for moisture percentage was found in T_4 (71.96) followed by T_3 (71.94), T_2 (71.86), T_1 (71.84) and T_0 (71.80). There were no significant differences found among the treatments. Thus, it showed that different levels of milk and strawberry juice have a great impact on the quality of fruit yoghurt. The highest mean value for total solids percentage was found in T_0 (28.22) followed by T_1 (28.18), T_2 (28.16), T_3 (28.08) and T_4 (28.00). There were no significant differences found among the treatments. F value was 0.0, indicating no significant effect of treatment on total solid. The highest mean value for fat percentage was found in T_0 (4.73) followed by T_1 (4.36), T_2 (4.12), T_3 (4.08) and T_4 (4.01). There were no significant differences found among the treatments. and the highest mean value for protein percentage was found in T_4 (4.41) followed by T_3 (4.34), T_2 (4.24), T_1 (4.15) and T_0 (3.87). There were no significant differences found among the treatments. The highest mean value for fat percentage was found in T_0 (0.79) followed by T_1 (0.76), T_2 (0.73), T_3 (0.70) and T_4 (0.69). There were no significant differences found among the

Table 4: Physical qualities of yoghurt evaluated by panel.

Sample no.	Treatments	Types of yoghurt	Colour	Body and texture	Flavour and taste
1.	T_0 (Control yoghurt)	Cow milk yoghurt	White	Smooth thin waxy	Pleasant sour
2.	T_1 (addition of 5% strawberry juice/pulp)	Cow milk yoghurt	Light pink	Smooth compact	Pleasant sour
3.	T_2 (addition of 10% strawberry juice/pulp)	Cow milk yoghurt	Light pink	Smooth compact	Pleasant sour
4.	T_3 (addition of 15% strawberry juice/pulp)	Cow milk yoghurt	Light pink	Smooth compact	Pleasant sour
5.	T_4 (addition of 20% strawberry juice/pulp)	Cow milk yoghurt	Light pink	Smooth compact	Pleasant sour

Table 5: Chemical quality of yoghurt.

Parameters*	Control and strawberry fruit juice yoghurt					Range (%)
	T_0 (0%)	T_1 (5%)	T_2 (10%)	T_3 (15%)	T_4 (20%)	
Moisture	71.80	71.84	71.86	71.94	71.96	71.80 - 71.96
Total solids	28.22	28.18	28.16	28.08	28.00	28.00 - 28.22
Fat	4.73	4.36	4.12	4.08	4.01	4.01 - 4.73
Protein	3.87	4.15	4.24	4.34	4.41	3.87 - 4.41
Ash	0.79	0.76	0.73	0.70	0.69	0.69 - 0.79
Acidity	0.8	0.9	0.9	1.00	1.02	0.8 - 1.02
Average	18.3683	18.365	18.335	18.3567	18.3483	18.335 - 18.3683

*mean values, n=3.

Table 6: Analysis of Variance (ANOVA) of five different samples of cow milk with treatments.

Sources of variation	Degrees of freedom	Sum of squares	M.S. (variance)	F Cal.	F.value at 5%
Between the groups	4	0.0043	0.0011	0.0	2.759
Within the groups (error)	25	19869.3704	794.7748		
Total	29	19869.3747			

treatments and the highest mean value for acidity percentage was found in T_4 (1.02) followed by T_3 (1.00), T_2 (0.9), T_1 (0.9) and T_0 (0.8). There were no significant differences found among the treatments.

Analysis of Variance (ANOVA) for the moisture, total solids, fat, protein, ash and acidity content in five different samples of cow milk (S1, S2, S3, S4 and S5) with treatments (T_0, T_1, T_2, T_3 and T_4) using different levels 0% (control yoghurt), 5%, 10%, 15% and 20% (with addition of strawberry juice) as shown in Table 5.

The null hypothesis (H_0) is accepted, since 2.759>0.0, (FT>FC). This means that, there is no significant difference between the mean of moisture, total solids, fat, protein, ash and acidity content in milk samples (Table 6).

CONCLUSION

This study was investigated on the basis of physico-chemical analysis of 0% (plain) and 5%, 10%, 15% and 20% level of strawberry juice yoghurt samples. With the increasing percentage of strawberry juice, there is also an increase in acidity percentage in yoghurt which shows that the physical quality of yoghurt samples is decreasing. Thus, the results obtained at 5% addition shows a better acceptance level and found to be best among all the treatments. In chemical analysis, nutritional quality decreases with the addition of strawberry juice. Future research may investigate by considering strawberry syrup and other varieties of strawberry fruits can be used.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

REFERENCES

Banerjee, U., Malida, R., Panda, R., Halder, T. and Roymahapatra, G. (2017). Variety of yogurt and its health aspects-a brief review. *International Journal of Innovative Practice and Applied Research*. **7(7):** 56-66.

Dwivedi, M., Rai, R.K. and Singh, P. (2024). Fungal diversity associated with strawberry fruit loss in the Gorakhpur division, U.P. India. *Agricultural Science Digest*. **1-9.** doi: 10.18805/ag.D-6170.

FAO. (2023). Agricultural Production Statistics 2000-2022. FAOSTAT Analytical Briefs, No. 79. Rome. https://doi.org/10.4060/cc9205en.

Faisal, M., Saifullah and Mukhriza, T. (2019). Organoleptic analysis of yogurt with banana addition and stevia sweeteners. *Rasayan Journal of Chemistry.* **12(3):** 1151-1156.

Felix, J., Bunkar, D.S. and Rose, H., (2022). Study on Consumer Acceptance of Biofortified Yoghurt in Varanasi Region, Uttar Pradesh, India. Research and Reviews. *Journal of Dairy Science and Technology*. **11(2):** 1-9.

Fisberg, M. and Machado, R. (2015). History of yogurt and current patterns of consumption. *Nutrition Reviews*. **73(1):** 4-7.

Govindammal D., Seethalakshmi, M., Thangaraj, S. (2017). An evaluation of physiochemical properties on aloevera gel fortified yoghurt. *Asian Journal of Dairy and Food Research.* **36(4):** 288-291. doi: 10.18805/ajdfr.DR-1244.

Jaster, H., Arend, G.D., Rezzadori, K., Chaves, V.C., Reginatto, F. H. and Petrus, J.C.C. (2018). Enhancement of antioxidant activity and physicochemical properties of yogurt enriched with concentrated strawberry pulp obtained by block freeze concentration. *Food Research International.* **104:** 119-125.

Kaur, R., Kaur, G., Mishra, S.K., Panwar, H., Mishra, K.K. and Brar, G.S. (2017). Yogurt: A nature's wonder for mankind. *International Journal of Fermented Foods*. **6(1):** 57-69.

Muttulani, J.A., Turnos, A.N. (2025). Postharvest quality and physico-chemical analysis of strawberry (*Fragaria ananassa* L.) to various application of mulching and organic fertilizers. *Bhartiya Krishi Anusandhan Patrika*. **40(2):** 187-193. doi: 10.18805/BKAP785.

Parnell, C.E.M., Kakuda, Y., Mullen, K., Arnott, D.R. and Deman, J.M. (1986). Physical properties of yogurt: A comparison of vat versus continuous heating systems of milk. *Journal of Dairy Science*. **69(10):** 2593-2603.

Rasic, J.L. and Kurmann, J.A. (1978). Yoghurt: Scientific Grounds, Technology, Manufacture and Preparation. Technical Dairy Publishing House, Berne.

Shree, S.T.C., Venkatesh, M.M., Praveen, A.R. and Teja, V. (2017). Effect of whey protein concentrate and fruit juice on sensory quality of enriched misti dahi. *Asian Journal of Dairy and Food Research*. **36(1):** 21-25. doi: 10.18805/ajdfr.v36i01.7455.

Shiby, V.K. and Mishra, H.N. (2013). Fermented milks and milk products as functional foods-A review. *Critical Reviews in Food Science and Nutrition*. **53(5):** 482-496.

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जो मनुष्य क्रोधी पर क्रोध नहीं करता बल्कि उसे क्षमा कर देता है, वह अपने और क्रोध करने वाले की संकट से रक्षा करता है। -वेद व्यास

इस अंक में

शोध लेख

शिक्षा एवं संस्कार के पोषण का त्रिभुज विद्यालय, परिवार एवं बाह्य समाज का साझा प्रयास

सुमन पाल
डॉ. विनोद कुमार

सारांश : विद्यार्थियों में बढ़ती अपराध प्रवृत्ति, चाहे वह किसी भी स्तर (प्राथमिक, माध्यमिक या उच्च शिक्षा) का विद्यार्थी हो, वर्तमान वैचारिक जगत की सबसे विचारणीय समस्याओं में से एक है। कहीं कोई विद्यार्थी अपनी माँ को केवल 'मोबाइल पर वीडियो गेम खेलने से मना करने पर' मार देता है, तो कहीं कोई विद्यार्थी अध्यापक के डांटने मात्र से, तो कहीं कोई विद्यार्थी किसी अन्य कारण से गलत रास्तों पर निकल पड़ता है। सामाजिक-सांस्कृतिक रूप से अस्वीकार, उत्तेजित और भड़काऊ ऑनलाइन सामग्री तक आसान पहुंच भी इसमें वृद्धि कर रहा है। भारत जैसे सबसे अधिक युवाओं वाले देश में सोशल मीडिया और सर्जनात्मक कृत्रिम बुद्धिमत्ता (जीएआई) के बढ़ते प्रभाव के इस दौर में यह समस्या और अधिक विकराल रूप धारण करती जा रही है। अब सवाल यह उठता है कि विद्यार्थियों के आपराधिक प्रवृत्ति का जिम्मेदार कौन है? विद्यार्थियों में सामाजिक- सांस्कृतिक विकास हेतु जिम्मेदार कौन है? वर्तमान सर्जनात्मक कृत्रिम बुद्धिमत्ता और सोशल मीडिया के बढ़ते प्रभाव के दौर में क्या परिवार/विद्यालय/बाह्य समाज अकेले श्रेष्ठ व्यक्तित्व का विकास करने में समर्थ है? या वर्तमान वैश्विक जरूरतों को परिपूर्ण करने लायक श्रेष्ठ व्यक्तित्त्व वाले सामाजिक- संस्कारित युवा के निर्माण में परिवार, विद्यालय और बाह्य समाज की साझा भूमिका है।

इसी महत्त्वपूर्ण सरोकार को केंद्र में रखकर पाल्यों (विद्यार्थियों) की शिक्षा और संस्कार के पोषण में परिवार, विद्यालय और बाह्य समाज की साझा भूमिका की विवेचना को इस आलेख में प्रस्तुत किया गया है।

यदि हम अपनी आने वाली पीढ़ी को शिक्षित और संस्कारवान बनाना चाहते हैं तो हमें यह समझना होगा कि समभाव और समतामूलक सामाजिक न्याय का दृष्टिकोण अपनाकर ही हम एक बेहतर समाज का निर्माण कर सकते हैं।

मूल लेख : एक शिशु, जो इस संसार में सबसे उत्तम दिल-दिमाग लेकर पैदा होता है। वह अपनी किलकारी मात्र से ही अपने आस-पास उपस्थित सभी के चेहरों पर मुस्कान बिखेर देता है। उसके मन में सभी के लिए प्यार ही प्यार होता है। वह ईर्ष्या-द्वेष, वैमनस्य, घृणा आदि से पूर्णतः अपरिचित होता है। वह किसी के प्रति किसी भी तरह की पूर्व-धारणा से ग्रसित नहीं होता है। आखिर अचानक से वह एक अपराधी जैसा व्यवहार कैसे कर बैठता है? या यूं कहें कि एक स्वस्थ समाज की नैतिक पराकाष्ठा के इतर रची गई अपराध तथा अनैतिक कृत्यों की परिभाषा में सम्मिलित व्यवहार कैसे करने लगता है? ज़रा सोचिए कि क्या इसके लिए वह अकेले जिम्मेदार है या हम-सब भी? यहां हम सब से हमारा तात्पर्य अभिभावक, परिवार-रिश्तेदार एवं पास-पड़ोस के लोगों तथा उसके विद्यालय के अध्यापक आदि से है। दरअसल वास्तविक सवाल यह है कि 'क्या विद्यार्थियों के आपराधिक एवं अनैतिक कार्य-व्यवहार में हम-सब की कोई भूमिका' है? यह एक गंभीर सवाल है। इस सवाल के विश्लेषण से ही शिक्षा एवं संस्कार की पोषण प्रक्रिया को संपूर्णता में समझा जा सकता है। यह सवाल अपने आप में ही उत्तर का विस्तार समाहित किए हुए है। वास्तव में उक्त सवाल का सटीक विश्लेषण किए बिना विद्यार्थियों के शिक्षा एवं संस्कार की पोषण प्रक्रिया को समझना आसान नहीं है, और विद्यार्थियों के शिक्षा एवं संस्कार की पोषण प्रक्रिया को समझे बिना उनकी अनैतिक एवं आपराधिक प्रवृत्ति

के पीछे की सैद्धांतिकी के वास्तविक सत्य को उजागर कर पाना संभव नहीं होगा। तो पहले विद्यार्थियों के शिक्षा एवं संस्कार की पोषण प्रक्रिया को समझते हैं। हम सभी इस बात से सहमत होंगे कि एक शिशु शैशवावस्था से लेकर देश का जिम्मेदार संवैधानिक नागरिक बनने के अपने विकासक्रम में दो सामाजिक-शैक्षिक संस्थाओं (परिवार और विद्यालय) में सबसे अधिक समय व्यतीत करता है।

परिवार पालन-पोषण करने के साथ ही साथ शिक्षा एवं संस्कार के पोषण का भी प्रथम केंद्र होता है और माता पहली शिक्षिका। माता के साथ ही साथ पिता, परिवार के अन्य सदस्य, पास-पड़ोस, मित्र एवं रिश्तेदार सभी मिलकर अपने पाल्य (बच्चा) की वृद्धि एवं विकास प्रक्रिया में योगदान करते हैं।प्रत्यक्ष और अप्रत्यक्ष रूप से उपर्युक्त सभी पाल्य के सामाजिक-सांस्कृतिक विकास को प्रभावित करते हैं। कहने का आशय मात्र इतना है कि शिशु अपने जीवन की शुरूआत उपरोक्त सभी लोगों के संपर्क में रहते हुए करता है और आगे भी इनके संपर्क में रहते हुए बाह्य समाज तथा अन्य संस्थाओं से जुड़ता जाता है। इस प्रकार उसका सामाजिक दायरा बढ़ने लगता है। लगभग पांच-छः वर्ष की अवस्था में वह विद्यालय जाना प्रारम्भ करता है तथा उसके जीवन में शिक्षक नामक सामाजिक रूप से बहुत सम्मानित और आदरणीय व्यक्तित्व का पदार्पण होता है। इसके उपरांत अभिभावक (परिवार सहित), अध्यापक (विद्यालय परिवार) और बाह्य-समाज (समुदाय) तीनों मिलकर बच्चों के वैश्विक नागरिक निर्माण की समुचित व्यवस्था हेतु एक अद्वितीय सामाजिक ताने-बाने वाले त्रिभुज का निर्माण करते हैं। इसे हम 'वैश्विक आवश्यकता के लिए शिक्षा और संस्कार के पोषण का त्रिभुज (Triangle of Nurturing Education and Values for Global Needs)' कह सकते हैं। इस त्रिभुज के केंद्र में विद्यार्थी के रूप में वही शिशु होता है। त्रिभुज की तीन भुजाएं क्रमशः परिवार, विद्यालय और बाह्य समाज को संदर्भित करते हैं। उक्त त्रिभुज के केंद्र में रहते हुए अर्थात् अभिभावक, अध्यापक एवं समुदाय के सानिध्य में रहकर वह जीवन-कौशल सीखना प्रारम्भ करता है। विद्यार्थी पर अपने अभिभावक और अध्यापक का सबसे अधिक प्रभाव पड़ता है। उसे किसके साथ कैसा व्यवहार करना है, किसको क्या कहकर सम्बोधित करना है, किसके साथ किस तरह पेश आना है, किसके पांव छूना है, किससे हाथ मिलाना है, किसके साथ उठना-बैठना है, किसके साथ नहीं इत्यादि को वह अपने घर-परिवार से सीखता है। अर्थात् विद्यार्थी सामाजिक-सांस्कृतिक तौर-तरीके घर-परिवार से सीखता है। हालांकि उसे यह सब कुछ सिखाने में विद्यालय की कार्य-संस्कृति भी महत्त्वपूर्ण भूमिका निभाती है। कभी-कभी ऐसा देखने को मिलता है कि विद्यार्थी घर में अपनी मम्मी को बताता है कि मेरी मैम ने कहा है 'कभी झूठ मत बोलना'। यह तो केवल एक प्रसंग मात्र है। वास्तव में विद्यार्थी के सामाजिक एवं नैतिक संस्कार बोध में अभिभावक एवं अध्यापक दोनों बहुत महत्त्वपूर्ण योगदान देते हैं। ऐसे में एक अध्यापक होकर हम सामाजिक पतन, बढ़ते भेदभाव के मामले, सामाजिक समावेशन की समस्या, शैक्षिक संस्थानों में अंक एवं ग्रेड प्रदान करने में लिंग, रंग-रूप, जाति, धर्म एवं क्षेत्र के आधार पर भेदभाव जैसी समस्याओं में अपनी जवाबदेही से कैसे इनकार कर सकते हैं। जब वैश्विक नागरिक निर्माण प्रक्रिया रूपी त्रिभुज की तीनों भुजाएं अर्थात् परिवार, समुदाय एवं विद्यालय अपने-अपने स्तर पर अपनी-अपनी ज़िम्मेदारी-जवाबदेही के प्रति पूर्णतः सजग नहीं होंगे तो विद्यार्थियों की आपराधिक उन्मुखता के लिए जवाबदेही किसकी होगी? इस पर ठहरकर गंभीरतापूर्वक विचार करने की जरूरत है।

जब एक विद्यार्थी किसी प्रांतीय/ राष्ट्रीय/ अंतरराष्ट्रीय स्तर की सफलता प्राप्त करता है, तो उसकी सफलता के लिए उसकी मेहनत के साथ ही साथ परिवार, विद्यालय और बाह्य समाज सभी अपने-अपने स्तर से खुद को जिम्मेदार बतलाने में कोई कोर-कसर नहीं छोड़ते हैं। यहां तक कि प्रचारित-प्रसारित करते हुए गौरवान्वित भी महसूस करते हैं। लेकिन जब कोई विद्यार्थी तात्कालिक सामाजिक-संवैधानिक आदर्शों/मानदंडों, नैतिक मूल्यों और प्रचलित कानूनों की अवहेलना करता है (जिसे हम आपराधिक कृत्य कहते हैं), तो परिवार, विद्यालय और बाह्य समाज अपनी जवाबदेही से पीछे क्यों हो जाते हैं? क्यों नहीं आगे बढ़कर यह स्वीकार करते हैं कि उसके आपराधिक कृत्य में जाने-अनजाने हम सभी भी शामिल हैं। जो विद्यार्थी ने आज अपराध किया है, क्या वह आज पहली बार अपराध किया है? क्या वह स्वयं से अपराध के लिए उन्मुख हो गया? क्या उसे उसके अपराध के परिणाम पहले से समुचित रूप में पता थे? यदि उक्त सवालों का गहराई से विश्लेषण करेंगे तो पाएंगे कि उसके ऐसे कृत्यों की शुरूआत के लिए शिक्षा और संस्कार के पोषण वाले त्रिभुज के तीनों शीर्षों पर विराजमान परिवार, विद्यालय और समाज सभी जिम्मेदार हैं। दरअसल हम केवल और केवल इतना कहना चाह रहे हैं कि जिस प्रकार एक विद्यार्थी की सफलता (सामाजिक-संवैधानिक रूप से सकारात्मक कार्य) के लिए शिक्षा और संस्कार के पोषण वाले त्रिभुज के तीनों शीर्षों पर विराजमान परिवार, विद्यालय और समाज सभी जिम्मेदार होते हैं उसी प्रकार किसी अन्य

विद्यार्थी के आपराधिक उन्मुखता के लिए भी शिक्षा और संस्कार के पोषण वाले त्रिभुज के तीनों शीर्षों पर विराजमान परिवार, विद्यालय और समाज सभी जिम्मेदार होते हैं। इसे ध्यान में रखकर ही विद्यार्थियों के अपराध का मूल्यांकन किया जाना चाहिए। अक्सर हम आपराधिक कृत्यों का बिना समुचित आलोचनात्मक विश्लेषण किए किसी अन्य कारक जैसे सोशल मीडिया, पश्चिमी प्रभाव, जलवायु परिवर्तन, सांस्कृतिक संक्रमण, धार्मिक उन्माद, संगत इत्यादि को कारण गिनाकर स्वयं को बहुत चालाकी से बचा लेते हैं। अपनी भूमिका और जवाबदेही पर चर्चा तक नहीं करते हैं। क्या पता परिवार, विद्यालय या समाज की ही किसी क्रियाकलाप अथवा गतिविधि का उस विद्यार्थी के अन्त:करण पर कोई बुरा प्रभाव पड़ा हो, जो आज आपराधिक कृत्य के रूप में हम सब के सामने प्रस्तुत हुआ हो या भविष्य में किसी भी प्रकार के आपराधिक कृत्य के रूप में प्रस्तुत हो सकता है।

ज़रा ठहरकर एक गहरी सांस लीजिए फिर शांत मन से सोचिए कि बच्चों में सामाजिक एवं नैतिक संस्कारों, मूल्यों एवं आदर्शों यथा- न्याय, समानता, तटस्थता, तार्किकता, वैज्ञानिक दृष्टिकोण, ईमानदारी, लालच न करना, अपनी मेहनत पर भरोसा रखना, सत्य भाषण, परोपकार, सहिष्णुता, प्रेम-लगाव, बड़ों का आदर करना, सभी से प्रेमपूर्वक बात करना, किसी से झगड़ा न करना, आपस में मिल-जुलकर एक साथ रहना, सुख-दु:ख में एक दूसरे का साथ देना, दूसरों की मदद करना, ऊंच-नीच की भावना न रखना, सभी का सम्मान करना, उत्तम आचरण करना, मनमानी न करना जैसे मानवीय गुणों का बीजारोपण करने की ज़िम्मेदारी किसकी है? या दूसरे अर्थों में यह कहें कि तथाकथित सामाजिक बुराइयों यथा- ईर्ष्या-द्वेष, ऊंच-नीच की भावना, रंग-रूप- लिंग-जाति-धर्म-क्षेत्र आधारित अहम और उक्त संबंधित पूर्वाग्रह एवं पक्षपात, अन्याय, अंधविश्वास तथा सामंती सोच इत्यादि से बच्चों को बचाने की ज़िम्मेदारी किसकी है? क्या सामाजिक-संवैधानिक रूप से श्रेष्ठ व्यक्तित्व वाले युवाओं (जिनमें उपर्युक्त सामाजिक बुराइयों और अनैतिकता का अभाव हो) का निर्माण केवल परिवार या विद्यालय या समाज अकेले कर सकता है? मेरी तरह क्या आप को भी अब यही लगने लगा है कि परिवार, विद्यालय और समुदाय शिक्षा और संस्कार के पोषण वाले त्रिभुज की तीन भुजाओं की तरह जब केंद्रक रूपी बच्चे को घेरे हुए हैं और उन्हीं तीनों का साझा प्रभाव बच्चे को ऐच्छिक-अनैच्छिक रूप से लगभग शत-प्रतिशत प्रभावित कर रहा है, तब उक्त सवालों के आलोक में सामाजिक-संवैधानिक संस्कार के बीजारोपण तथा सामाजिक बुराइयों से बचाव हेतु नि:स्संदेह रूप से जवाबदेह परिवार, विद्यालय एवं बाह्य समाज तीनों ही हैं। इसीलिए कोठारी आयोग को यह कहना पड़ा था कि समाज का निर्माण कक्षाओं में होता है।

हम सभी अध्यापकों को ध्यान रखना चाहिए कि एक उत्तम समाज (किसी भी तरह के भेदभाव से रहित) का निर्माण एक समतामूलक, समावेशी और वास्तविक-व्यावहारिक रूप से विद्यार्थी केन्द्रित कक्षा (जिसमें किसी भी समुदाय से संबंधित, कोई भी भाषा बोलने वाले तथा किसी भी जेंडर के विद्यार्थी के लिए समतापूर्ण वातावरण) से ही हो सकता है। शिक्षा नीति-1986 में विद्यालयों को सामुदायिक सहयोग एवं संलग्नता बढ़ाने हेतु प्रयास करने की बात कही गई लेकिन काम बना नहीं या यह कह लें कि विद्यालयों ने समुदाय से जुड़ने की पुरजोर कोशिश नहीं की। लिहाज़ा समुदाय द्वारा सम्पूर्ण जवाबदेही अकेले विद्यालय पर मढ़ दी गई, जबकि बच्चों के भावी सामाजिक नागरिक बनाने की प्रक्रिया में परिवार और समुदाय भी बराबर के भागीदार होते हैं।

बच्चों के बनने या बिगड़ने की जो शब्दावली प्रयुक्त होती है, उसके तीन आधार-परिवार, विद्यालय और समाज होते हैं। यही तीनों आधार मिलकर बच्चे को भावी नागरिक के रूप में तब्दील करते हैं। कहने का आशय मात्र इतना है कि तीनों आधारों में सामंजस्य, समन्वय एवं आपसी तालमेल के साथ सहयोग के बिना बच्चों को श्रेष्ठ सामाजिक नागरिक बना पाना असंभव है।

सामान्य अर्थों में बच्चों के बनने या बिगड़ने की जो शब्दावली प्रयुक्त होती है, उसके तीन आधार- परिवार, विद्यालय और समाज होते हैं। यही तीनों आधार मिलकर बच्चे को भावी नागरिक के रूप में तब्दील करते हैं। कहने का आशय मात्र इतना है कि तीनों आधारों में सामंजस्य, समन्वय एवं आपसी तालमेल के साथ सहयोग के बिना बच्चों को श्रेष्ठ सामाजिक नागरिक बना पाना असंभव है। इसीलिए राष्ट्रीय शिक्षा नीति-2020 में सामुदायिक सहभागिता को शैक्षिक क्रियाविधि का अनिवार्य अंग के रूप में स्वीकार किया गया है। वर्तमान समय में संस्कार विहीन शिक्षा का कोई औचित्य नहीं है। शिक्षा और संस्कार से ही विद्यार्थियों

में नैतिक मूल्यों का विकास होता है। उत्तम आचरण एवं चरित्र के विकास हेतु विद्यालयों में 'नैतिक शिक्षा' को अलग से एक विषय के रूप में पढ़ाया जाता है। अध्यापकगण नियमित शिक्षण-अधिगम प्रक्रिया के साथ ही नैतिक आचार-विचार को व्यवहार में शामिल करने की प्रेरणा देते रहते हैं। राष्ट्रीय त्योहारों यथा- गणतन्त्र दिवस, स्वतन्त्रता दिवस एवं गांधी जयंती, बाल दिवस, शिक्षक दिवस, हिन्दी दिवस तथा अन्य विशेष अवसरों पर विद्यालयों में विभिन्न प्रकार के शैक्षिक-सांस्कृतिक कार्यक्रमों का आयोजन किया जाता रहता है। इनके अतिरिक्त विचार गोष्ठी, संस्कारशाला, वाद-विवाद एवं पोस्टर प्रतियोगिता आदि का भी आयोजन किया जाता है। आवश्यकता इस बात की है कि उक्त कार्यक्रमों को सामाजिक-संवैधानिक मूल्यों से जोड़कर नैतिक मूल्यों का विकास करने हेतु व्यक्तित्त्व विकास और कौशल विकास पर अधिक ध्यान दिया जाये। ताकि विद्यार्थीगण न केवल सामाजिक-संवैधानिक मूल्यों को समझें बल्कि राष्ट्रहित में सकारात्मक भावनाओं से ओतप्रोत हो सकें। इसके माध्यम से विद्यार्थीवृंद नैतिक व्यवहार-आचरण एवं विभिन्न प्रकार के संस्कार भी सीखेंगे। कभी-कभी कुछ सामाजिक संगठनों द्वारा बाल शिविर का आयोजन भी किया जाता है, जिनमें हम सभी अपने-अपने पाल्यों को साथ में ले जाकर प्रतिभाग कर सकते हैं। यह सामाजिक संगठनों का वर्तमान परिप्रेक्ष्य में बहुत ही सार्थक प्रयास है। क्योंकि बालकों के बनने-बिगड़ने में समाज का भी योगदान होता है। इसलिए हमें अपने सामाजिक दायित्वों का भी श्रेष्ठतम निर्वहन करना चाहिए। अक्सर यह देखा जाता है कि हम अपने बच्चों-विद्यार्थियों के साथ तो बहुत शालीन व्यवहार करते हैं लेकिन दूसरों के साथ हम जल्दी ही अपना आपा खो- बैठते हैं तथा नैतिक, संस्कारित, आदर्श एवं मूल्ययुक्त व्यवहार वाले पथ से विचलित हो जाते है। पता नहीं क्यूं हम-सभी सब कुछ जानते-समझते हुए भी, अपने एवं दूसरे बच्चों के बीच एक समान व्यवहार नहीं कर पाते हैं, जबकि हमें मालूम है कि इसका दोनों बच्चों (हमारे एवं अन्य) पर एक समान कुप्रभाव पड़ रहा है। क्योंकि बच्चे हमारे-आप के व्यवहार-संगत आचरण से स्वत: सीखते रहते है और इसका हमें पता भी नहीं चलता है। इसलिए हम सभी को अन्य बच्चों के साथ भी वैसा ही व्यवहार करने की महती आवश्यकता है, जैसा कि हम अपने पाल्यों-विद्यार्थियों के साथ करते हैं। क्योंकि देश एवं समाज की उन्नति में सभी बच्चे अपना-अपना योगदान देंगे। यदि एक भी बच्चा अनैतिक व्यवहार सीख गया तो संभव है कि उसका प्रभाव हमारे पाल्यों पर भी पड़े, जैसा कि वर्तमान समय में दिखाई पड़ रहा है। अत: हम सभी को घर, पास-पड़ोस, कार्य-स्थल, सार्वजनिक स्थानों पर अर्थात् प्रत्येक जगह जहां कहीं भी, जिस भी रूप में रहें, हमारी कोशिश अपने आदर्श व्यवहार के माध्यम से हमेशा एक सकारात्मक उदाहरण पेश करने की होनी चाहिए। तभी हम सभी अपने विभिन्न भूमिकाओं (अभिभावक, अध्यापक एवं सामाजिक सदस्य के रूप में) का उत्तम निर्वहन करते हुए, अपने देश के भविष्य (बच्चों) को संस्कारवान बना सकते हैं।

लेकिन क्या हम सभी उन संस्कारों, मूल्यों एवं आदर्शों को अपने दैनिक जीवन में स्वयं के व्यवहार में लाते है? क्या हम सभी अपने घर-परिवार, कार्यालय, विद्यालय जैसे निजी एवं सार्वजनिक जगहों पर ईमानदारीपूर्वक नैतिक आचरण करते हैं? जिन संस्कारों, मूल्यों एवं आदर्शों को हम दूसरों के व्यवहार में देखना चाहते हैं, क्या उन्हें हम सभी स्वयं के आचरण में लाकर अपने व्यवहार से परिलक्षित नहीं करा सकते है? ये कुछ ऐसे विशिष्ट सवाल है, जिनका उत्तर ढूंढने हेतु हमें किसी बड़े ग्रंथ या गुरु की शरण में जाने की आवश्यकता नहीं है। उक्त सवालों के उत्तर के लिए यदि कुछ आवश्यक है, तो केवल अपनी 'आत्मा की आवाज' सुनना तथा उसी के अनुसार अपने व्यवहार को संयमित करने की। क्योंकि मेरा यह स्पष्ट मानना है कि हम-सभी अभिभावक एवं अध्यापकवृंद मिल-करके भी, अपने पाल्यों (विद्यार्थियों) को जो संस्कार, नैतिक मूल्य एवं आदर्श नहीं सीखा पाते है, उन्हें भी हम महज स्वयं के व्यवहार में शामिल करके अपने बच्चों को सीखा सकते हैं। क्योंकि आचरण का प्रभाव बहुत गुप्त लेकिन गहरा पड़ता है। जब हम सभी, जो कुछ भी अपने बच्चों को सिखाना चाहते हैं, वह अपने व्यवहार में लायेंगे तो वे (बच्चे) हमारे व्यवहार को देखकर स्वत: वैसा व्यवहार करना सीख लेंगे। अत: हमें बच्चों को नैतिक मूल्य सिखाने के बजाय अपने दैनंदिन कार्य-व्यवहार में नैतिक आचरण करने की आवश्यकता है। हम स्वयं यदि अपने कार्य-दायित्व के निर्वहन में नैतिक मूल्यों का पालन करेंगे तो उसे बच्चों को सिखाने की ज़रूरत ही नहीं पड़ेगी, वे स्वयं सीख लेंगे और यदि हम अपने जीवन में नैतिक आचरण का निर्वहन नहीं कर सकते तो हमें बच्चों को या यूं कहें कि किसी को भी नैतिक आचरण का निर्वहन एवं नैतिक मूल्यों का पालन हेतु कहने-सिखाने का कोई अधिकार नही है। अब मुझे गांधी याद आते है। गांधी जी ने अपने जीवन में कभी कोई ऐसा उपदेश नहीं दिया, जिसका वे स्वयं पालन न करते हों। एक बार एक महिला अपने पाल्य (जो गुड़ बहुत खाता था) के साथ गांधी जी के पास आकार कहती है कि महात्मा जी हमारा बेटा गुड़ बहुत खाता है, कृपया कुछ उपाय

बताएं। गांधी जी ने कहा कि आप 15 दिन बाद आयें। जब 15 दिन बाद गांधी जी ने उस महिला के साथ आए बच्चे से केवल इतना कहा कि 'बेटा अधिक गुड़ नहीं खाना चाहिए; यह स्वास्थ्य के लिय हानिकारक होता है'। तब वह महिला आश्चर्यचकित होकर बापू से पूछती है- महात्मा जी यह तो आप उस दिन भी बता सकते थे लेकिन 15 दिन का अंतराल क्यूं? गांधी जी ने जो जवाब दिया, वह केवल उन्हीं के जैसा महान व्यक्तित्व दे सकता है। गांधी जी ने कहा कि तब (15 दिन पहले) मैं, स्वयं बहुत गुड़ खाता था। जो व्यवहार मैं स्वयं करता था, उसे छोड़ने का दूसरों को उपदेश कैसे दे सकता था। इसलिए मैंने 15 दिन का समय लिया, अपनी उस आदत को सुधारा फिर आज विद्यार्थी को उपदेश देने में सक्षम हुआ। इस संसार की तमाम बुराइयों को दूर करने में गांधी जी का जीवन-दर्शन एक मिसाल है। गांधी जी भारतीय शिक्षा एवं संस्कार के सजीव उदाहरण हैं। आवश्यकता केवल इस बात की है कि हम सभी गांधी जी के जीवन-दर्शन से नैतिक-मूल्यों, आदर्शों एवं संस्कारों को सीखकर उसे स्वयं के कर्तव्य-व्यवहार में अनुप्रयुक्त करें। परिणामस्वरूप हम सभी देश के भविष्य (नौनिहालों) को शिक्षित एवं संस्कारवान बनाने में सक्षम हो सकेंगे। इसीलिए भारतीय ज्ञान परंपरा को अंगीकार करते हुए राष्ट्रीय शिक्षा नीति-2020 में शिक्षा एवं संस्कार के पोषण हेतु विद्यालय को परिवार और बाह्य समाज से जुड़ने हेतु प्रोत्साहित किया गया है।

निष्कर्ष : अपनी एक बहुमूल्य सारगर्भित जैविक पहचान के साथ पैदा हुआ बच्चा, परिवार रूपी संस्था में रहकर माता-पिता, अन्य परिवारजन और रिश्तेदारों-परिचितों के साथ भाषायी और गैर-भाषायी अंत:क्रिया करते हुए अपनी सामाजिक-सांस्कृतिक पहचान का विकास करता है। बचपन में परिवार रूपी संस्था, बच्चे का सामाजिक और सांस्कृतिक विकास करने में सर्वाधिक महत्त्वपूर्ण भूमिका का निर्वहन करता है। एक निश्चित आयु के बाद वही बच्चा विद्यार्थी के रूप में विद्यालय रूपी संस्था में प्रवेश करता है और अपने सामाजिक-सांस्कृतिक संदर्भ सहित, अपनी आयु वर्ग के अन्य सहपाठियों के साथ अन्त:क्रिया करते हुए विद्यालयी परिवार के सदस्यों (अध्यापकों इत्यादि) के नेतृत्व में अपने सामाजिक-सांस्कृतिक संदर्भ का अग्रतर विकास और मज़बूत करते हुए एक संवैधानिक नागरिक बनने की ओर उन्मुख होता है। इस प्रकार पाल्यों का एक संवैधानिक नागरिक बनने की प्रक्रिया में घर-परिवार और विद्यालय के साथ ही साथ बाह्य समाज की भी महत्त्वपूर्ण भूमिका होती है। विद्यार्थियों के शिक्षा एवं संस्कार का पोषण इन्हीं तीनों संस्थानों के साझा प्रयास द्वारा सुनिश्चित होता है। क्योंकि परिवार, विद्यालय और बाह्य समाज तीनों मिलकर विद्यार्थियों के मनो-संज्ञानात्मक विकास के साथ ही साथ सामाजिक-सांस्कृतिक और वैश्विक नागरिकता विकास को भी प्रभावित करते हैं। परिवार, विद्यालय और बाह्य समाज मिलकर एक ऐसे त्रिभुज का निर्माण करते हैं, जिसके केंद्र में विद्यार्थी होता है और परिवार, विद्यालय और बाह्य समाज त्रिभुज की तीनों भुजाओं के रूप में उसे घेरे रहते हैं। यही घेराव शिक्षा एवं संस्कार के पोषण हेतु बेहतर वातावरण का निर्माण करता है। इस त्रिभुज रूपी पारिस्थितिकी तंत्र में विद्यार्थी अंत:क्रिया करते हुए शिक्षा और संस्कार के पोषण को सुनिश्चित करता है। अत: यदि हम अपनी आने वाली पीढ़ी को शिक्षित और संस्कारवान बनाना चाहते हैं तो हमें यह समझना होगा कि समभाव और समतामूलक सामाजिक न्याय का दृष्टिकोण अपनाकर ही हम एक बेहतर समाज का निर्माण कर सकते हैं। इसके लिए जरूरी है कि बच्चे के सामाजीकरण और शिक्षा एवं संस्कार के पोषण संबंधी गतिविधियों का क्रियान्वयन परिवार, विद्यालय और बाह्य समाज तीनों संस्थाएं उस त्रिभुज की तीनों भुजाओं की तरह मिलकर एक सारगर्भित संवैधानिक लक्ष्य की प्राप्ति हेतु साझा प्रयास सुनिश्चित करें, जिसके केंद्र में रहकर बच्चा अपना सर्वोत्तम सर्वांगीण विकास सुनिश्चित करते हुए अपना सामाजिक-सांस्कृतिक पहचान निर्मित करने में सक्षम हो सकें।

संदर्भ :

- कुमार, वि. (2020). वैश्विक चुनौतियों के समाधान में गांधी दर्शन की उपयोगिता. मीरायन, 13 (4). पृष्ठ: 52-58.
- राष्ट्रीय शिक्षा नीति (2020), शिक्षा मंत्रालय, भारत सरकार, नई दिल्ली.
- कुमार, वी. एवं ठाकुर, जी. के. (2019). गांधी का शिक्षा दर्शन एवं आदर्श नागरिक निर्माण. शैक्षिक उन्मेष, 3 (1). पृष्ठ : 15-28.
- शिक्षा पर राष्ट्रीय नीति (1986), भारत सरकार, नई दिल्ली।
- कोठारी आयोग (1964-66) रिपोर्ट।
- गांधी, एम. के., हिन्द स्वराज्य, अनुवादक- अमृतलाल ठाकोरदास नाणावटी, अहमदाबाद : नवजीवन प्रकाशन मंदिर.
- मोदी, एन. पी. (2017), गांधी दर्शन- सामाजिक सन्दर्भ, नई दिल्ली : शिल्पायन प्रकाशन.
- बसु, एन. के., गांधी जी क्या चाहते थे? अनुवादक, मदन लाल जैन (2014), वाराणसी : सर्व सेवा संघ प्रकाशन।

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मुसहर समुदाय की सामाजिक-आर्थिक अस्मिता और आजीविका का सवाल

सुमन पाल*, गोपाल कृष्ण ठाकुर† एवं विनोद कुमार‡

मुसहर समुदाय, जो मुख्य रूप से बिहार, उत्तर प्रदेश और नेपाल के कुछ हिस्सों में पाया जाता है;भारत के सबसे अधिक हाशिए पर रहने वाले समुदायों में से एक है। यह शोध पत्र भारत में मुसहर समुदाय की सामाजिक-आर्थिक अस्मिता और उनकी आजीविका के साधन अर्थात जीवन-यापन के तौर-तरीकों की गहरी पड़ताल को प्रस्तुत करता है। इस लेख में शोधार्थी द्वारा उत्तर प्रदेश के भदोही जिले के ग्राम पंचायत- मतेथु के मुसहर समुदाय का किए गए नृजातीय अध्ययन संबंधित अन्तर्दृष्टि भी सम्मिलित है। शोध परिणाम से स्पष्ट है कि मुसहर समाज की अपनी खान-पान, रहन-सहन की स्थिति और उनकी लोक परंपराएँ उन्हें विशिष्ट बनाती हैं। सदियों से सामाजिक और आर्थिक रूप से पिछड़े रहे इस समुदाय को सामाजिक बहिष्कार, गरीबी और अशिक्षा जैसी कई चुनौतियों का सामना करना पड़ा है। मुसहर समुदाय को अपने परिवेश में जाति और ऊंच-नीच की भावना आधारित व्यवस्था के कारण अक्सर भेदभाव का शिकार होना

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पड़ता है। कई अन्य जातीय समुदायों की तरह उन्हें भी अछूत माना जाता है। उनके लिए शिक्षा, रोजगार, सामाजिक न्याय और बुनियादी सुविधाओं तक पहुंच आसान नहीं है। उन्हें अक्सर गांवों के किनारे, मुख्य बस्तियों से अलग बस्तियों में रहने के लिए मजबूर किया जाता है। वे पत्तल बनाने तथा मिट्टी काटने में बेहद कुशल होते हैं। उन्हें खेतों, भट्ठों, बिल्डिंग मटेरियल की दुकानों और संभ्रांत लोगों के घरों में दैनिक मजदूरी करके जीवन-यापन करना पड़ता है। उत्तर प्रदेश में मुसहर समुदाय की सामाजिक-आर्थिक परिस्थितियां अनुसूचित जाति वर्ग की अन्य जातियों की तुलना में बहुत ही निम्न स्तर की हैं। उनका सामाजिक-आर्थिक समावेशन भी बहुत ही कम हुआ है। अवसर, धन और आय में भारी असमानता है। आज भी मुसहर समुदाय के साथ सामाजिक अस्पृश्यता और मुख्य समाज से बहिष्करण की स्थिति बनी हुई है।

बीज शब्द - मुसहर समुदाय, सामाजिक-आर्थिक अस्मिता, आजीविका एवं जीवन-यापन कौशल।

प्रस्तावना

भारत में अनुसूचित जाति की संकल्पना आजादी से पहले की है। वर्ष-1931 की जनगणना के आधार पर साइमन कमीशन ने सभी अछूत जातियों या समाज में सबसे निचले पायदान पर रह रही जातियों के समूह को 1935 में अनुसूचित जाति नाम दिया था। आजादी के बाद भारतीय संविधान अनुच्छेद-341 के अंतर्गत अनुसूचित जाति की सूची से नई जातियों को जोड़ने या पुरानी जाति को हटाने की शक्ति राष्ट्रपति को प्रदान करता है (प्रसाद एवं यादव, 2021)। सामाजिक न्याय एवं अधिकारिता मंत्रालय, भारत सरकार की रिपोर्ट- हैंडबुक ऑन सोशल वेलफेयर स्टेटिस्टिक्स-2021 के अनुसार 26 अक्टूबर, 2017 तक भारतीय संविधान के अनुच्छेद-341 में अनुसूचित जाति के अंतर्गत सम्मिलित समस्त जातियों की संख्या कुल 1284 है। उन्हीं 1284 अनुसूचित जातियों के समूह को महात्मा गांधी जी ने 'हरिजन' नाम दिया था। भारतीय वर्ण व्यवस्था में अनुसूचित जातियों को शूद्र एवं अति शूद्र भी कहा गया है। अनुसूचित जतियों के लिए एक बहुत ही प्रचलित शब्दावली है - दलित। दलित शब्द का प्रयोग भारतीय समाज में दबे-कुचले, वंचित और हाशिए पर रहने वाली जातियों के लिए किया जाता है। दरअसल दलित जातियाँ सामाजिक संरचना, कर्म आधारित वर्ण-व्यवस्था का जाति आधारित हो जाने और शैक्षिक-आर्थिक स्थिति इत्यादि कारणों से भेदभाव की शिकार रही हैं और उन्हें पूर्व में अछूत कहा जाता था। वर्तमान समय में भी अनुसूचित जातियों की स्थिति में बहुत सुधार नहीं हो पाया है। उन्हीं 1284 अनुसूचित जातियों में से एक अत्यधिक दबी-कुचली और मुख्य समाज से कटी हुई जाति है-मुसहर। मुसहर समुदाय सामाजिक संरचना के आधार पर एक ऐसे समूह का निर्माण करती है, जो अन्य समाज से कटा हुआ हाशिये पर है। यदि भारत के संदर्भ में देखा जाये तो मुसहर समुदाय का निवास अधिकांशत: उत्तर भारत में पाया जाता है। 'मुसहरों को सदा, मांझी, मंडल, भुईया, रिक्यासन, ऋषिदेव, बलाकुमुनी, दैयतानिया, कसमेटा, वनमानुष जैसे विभिन्न नामों से भी संबोधित किया जाता है' (कुमार,

2017)। मुसहरों को उत्तर प्रदेश के प्रयागराज, भदोही, जौनपुर जैसे जिलों में, वरुणा नदी के तटीय इलाकों में और इन जिलों के मध्यम और दक्षिणी भागों में वनवासी एवं वनों का राजा भी कहा जाता है। मुसहर समाज की अपनी खानपान, रहन-सहन की स्थिति और उनकी लोक परंपराएँ भी उन्हें विशिष्ट बनाती हैं। मुसहरों की सामाजिक-आर्थिक स्थिति को समझने के लिए बहुत कम जानकारी उपलब्ध है। मुसहरों का कोई अपना लिखित धर्म ग्रंथ नहीं है। उनकी परंपराएँ भी केवल मौखिक अभिव्यक्ति मात्र है, जो सदियों से पीढ़ी दर पीढ़ी केवल सुनकर और अनुकरण के माध्यम से चली आ रही हैं। मुसहर समुदाय की सामाजिक-आर्थिक परिस्थितियां अनुसूचित जाति वर्ग की अन्य जातियों की तुलना में बहुत ही निम्न स्तर की है। आज भी मुसहर समुदाय के साथ अस्पृश्यता जैसी भावना बनी हुई है। अन्य जातियों की तुलना में मुसहर समुदाय का सामाजिक समावेशन बहुत कम है। प्रस्तुत शोध पत्र में उत्तर प्रदेश के मुसहर समुदाय की सामाजिक-आर्थिक अस्मिता और उनकी आजीविका के साधन अर्थात जीवन-यापन के तौर-तरीकों का विश्लेषणात्मक वर्णन प्रस्तुत किया गया है।

भारत में मुसहर समुदाय की जनांकिकी

अंतरराष्ट्रीय रूप से मुसहर समुदाय मुख्यत: भारत और नेपाल में निवास करता है। नेपाल के तराई इलाकों में इनकी अच्छी-ख़ासी जनसंख्या निवास करती है। भारत में मुसहर समुदाय मुख्यत: उत्तर और मध्य-पूर्वी राज्यों यथा- उत्तराखंड, उत्तर प्रदेश, मध्य प्रदेश, बिहार, झारखंड, उड़ीसा, बंगाल और त्रिपुरा में पाया जाता है। 'उत्तर प्रदेश के मध्य और पूर्वी जिलों में फैले मुसहर पत्तल बनाने तथा मिट्टी काटने में बेहद कुशल होते हैं (जोशी एवं कुमार, 2022)'। मुसहरों की सबसे अधिक संख्या बिहार राज्य में है और दूसरे स्थान पर इनकी संख्या उत्तर प्रदेश में है। बिहार राज्य में तो मुसहर समुदाय को महादलित की श्रेणी में रखा है; जबकि उत्तर प्रदेश में मुसहर समुदाय आज भी अनुसूचित जाति समूह में ही सम्मिलित है। विभिन्न राज्यों में सम्पूर्ण एवं अनुसूचित जाति के सापेक्ष मुसहरों की जनसंख्या को बार तालिका 1 में प्रस्तुत किया गया है-

तालिका 1

सम्पूर्ण, अनुसूचित जाति वर्ग एवं मुसहर समुदाय की जनसंख्या

	बिहार	झारखंड	उड़ीसा	त्रिपुरा	उत्तर प्रदेश	उत्तराखंड	बंगाल	भारत
मुसहर समुदाय की जनसंख्या	2725114	53096	57	327	257135	718	20949	3057396
अनुसूचित जाति की जनसंख्या	16567325	3985644	7188463	654918	41357608	1892516	21463270	201378372
कुल जनसंख्या	104099452	32988134	419742178	3673917	199812341	10086292	91276115	1210854977

स्रोत: हैंडबुक ऑफ सोशल वेलफेयर स्टेटिस्टिक्स 2021, सामाजिक न्याय मंत्रालय, भारत सरकार पृष्ठ : 29 व 61-114 पर उपलब्ध प्रदत्तों की सहायता से एम.एस. एक्सेल-2021 सॉफ्टवेयर का उपयोग करके शोधार्थी द्वारा निर्मित

तालिका 1 के अवलोकन से स्पष्ट है कि भारत में मुसहर समुदाय की कुल संख्या लगभग 30 लाख 60 हजार (30,57,396) है। राज्यों में मुसहर समुदाय की सर्वाधिक संख्या, लगभग 27 लाख 25 हजार (27,25,114) बिहार में है, जो कि कुल मुसहर आबादी (30,57,396) का लगभग 89 प्रतिशत है। यद्यपि मुसहर समुदाय की जनसंख्या के आधार पर बिहार के बाद उत्तर प्रदेश दूसरे पायदान पर है, जिसमें लगभग 2 लाख 57 हजार (2,57,135) मुसहर निवास करते हैं, जो कि कुल मुसहर आबादी (30,57,396) का लगभग 8 प्रतिशत है तथापि कुल जनसंख्या के आधार पर उत्तर प्रदेश प्रथम पायदान पर है। मुसहर समुदाय की जनसंख्या के आधार पर राज्यों का बढ़ता क्रम उड़ीसा (0.002 प्रतिशत), त्रिपुरा (0.011 प्रतिशत), उत्तराखंड (0.023 प्रतिशत), पश्चिम बंगाल (0.685 प्रतिशत), झारखंड (1.737 प्रतिशत), उत्तर प्रदेश (8.410 प्रतिशत) और बिहार (89.132 प्रतिशत) है। मुसहर समुदाय की सबसे कम जनसंख्या उड़ीसा (57), त्रिपुरा (327) और उत्तराखंड (718) है। 'वर्ष 1981 की जनगणना के अनुसार उत्तर प्रदेश में मुसहर समुदाय की आबादी 126088 थी,जो कि 2011 तक 257135 हो गई है; जिन्हें वनमानुस, बंजारा और गोनारे भी कहा जाता था। उत्तर प्रदेश में वर्ष 1981 की मुसहर आबादी की तुलना में 2011 तक मुसहरों की जनसंख्या में लगभग 104 प्रतिशत की वृद्धि हुई है' (नारायण,2018)। मुसहर समुदाय की ग्रामीण एवं शहरी परिवेश में जन-सांख्यिकी को महिला-पुरुष के आधार पर क्रमशः तालिका द्वितीय एवं तृतीय में प्रस्तुत किया गया है -

तालिका 2

मुसहर समुदाय की ग्रामीण जन-सांख्यिकी

	बिहार	झारखंड	उड़ीसा	त्रिपुरा	उत्तर प्रदेश	उत्तराखंड	बंगाल	योग
ग्रामीण जनसंख्या	2631683	45814	24	225	249234	521	17432	2944929
ग्रामीण जनसंख्या	1272284	22362	4	99	120205	235	8513	1423698
ग्रामीण जनसंख्या	1359399	23452	20	126	129029	286	8919	1521231

स्रोत : हैंडबुक ऑफ सोशल वेलफेयर स्टेटिस्टिक्स 2021, सामाजिक न्याय मंत्रालय, भारत सरकार पृष्ठ : 115-168 तक उपलब्ध आवश्यक प्रदत्तों की सहायता से एम.एस. एक्सेल-2021 सॉफ्टवेयर का उपयोग करके शोधार्थी द्वारा निर्मित

तालिका 3

मुसहर समुदाय की शहरी जन-सांख्यिकी

	बिहार	झारखंड	उड़ीसा	त्रिपुरा	उत्तर प्रदेश	उत्तराखंड	बंगाल	योग
शहरी जनसंख्या	93431	7282	33	102	7901	197	3517	112463
शहरी जनसंख्या	45273	3483	16	50	3781	86	1728	54417
शहरी जनसंख्या	48158	3799	17	52	4120	111	1789	58046

स्रोत : हैंडबुक ऑफ सोशल वेलफेयर स्टेटिस्टिक्स 2021, सामाजिक न्याय मंत्रालय, भारत सरकार पृष्ठ : 169-222 तक उपलब्ध आवश्यक प्रदत्तों की सहायता से एम.एस. एक्सेल-2021 सॉफ्टवेयर का उपयोग करके शोधार्थी द्वारा निर्मित

उपर्युक्त तालिका 2 एवं 3 के अवलोकन से स्पष्ट है कि मुसहर समुदाय की कुल ग्रामीण जनसंख्या लगभग 29 लाख 45 हजार (2944929) है, जो कि मुसहर समुदाय की

कुल जनसंख्या (30,57,396) का 96 प्रतिशत है। इसमें पुरुष लगभग 15 लाख 21 हजार (1521231) अर्थात 52 प्रतिशत और महिला लगभग 14 लाख 24 हजार (1423698) अर्थात 48 प्रतिशत हैं। इसी प्रकार कुल शहरी जनसंख्या लगभग एक लाख 12 हजार (112463) है, जो कि मुसहर समुदाय की कुल जनसंख्या (30,57,396) का केवल 4 प्रतिशत है। इसमें पुरुष लगभग 58 हजार (58046) अर्थात 52 प्रतिशत तथा महिला लगभग 54 हजार (54417) अर्थात 48 प्रतिशत हैं। मुसहर समुदाय की शहरी जनसंख्या की तुलना में ग्रामीण जनसंख्या बहुत अधिक है। उड़ीसा को छोड़कर अन्य सभी राज्यों में मुसहर समुदाय की ग्रामीण जनसंख्या उनकी शहरी जनसंख्या से अधिक है। उड़ीसा में इसका उलट है। उड़ीसा एक मात्र ऐसा राज्य है, जहाँ मुसहर समुदाय की ग्रामीण जनसंख्या (24) उनकी शहरी जनसंख्या (33) से 27.27 प्रतिशत कम है।

मुसहर समुदाय और लिंगानुपात

किसी भी समाज के बेहतरी को मापने के पैमाने का एक महत्त्वपूर्ण घटक महिला-पुरुष की संख्या का अनुपात होता है। इसे सैद्धान्तिक रूप से प्रति एक हजार पुरुष पर महिलाओं की संख्या के आधार पर मापा जाता है। इससे समाज में हो रहे लैंगिक भेदभाव और लैंगिक पूर्वाग्रह का अंदाजा लगाया जाता है। इससे यह भी पता चलता है कि संबंधित समाज लैंगिक दुराग्रह से कितना मुक्त है और उस समाज में महिलाओं की स्थिति कैसी है। यदि यह अनुपात अधिक है तो सामान्यत: यह मान लिया जाता है कि महिलाओं की स्थिति बेहतर होगी। हालांकि महिलाओं की बेहतर स्थिति के आकलन के अन्य घटक भी हैं। सामान्यत: मुसहर समुदाय में लिंगानुपात अच्छा है। अन्य समुदायों की तुलना में 'मुसहर समुदाय में लिंगानुपात की स्थिति ठीक है' (कुमारी, 2020)। मुसहर समुदाय में महिलाओं को लगभग बराबरी का दर्जा प्राप्त है। वे घर-परिवार के साथ-साथ बाहर भी अपने पुरुष साथी ख़ासकर पति के साथ हमेशा रहती हैं। मुसहर समुदाय में पति-पत्नी का संबंध बहुत गहरा होता है। वे काम पर भी जाते हैं, तो साथ-साथ। इसके परिणामस्वरूप उनमें बालक-बालिका के जन्म पर कोई विशेष अंतर नहीं पड़ता है।

तालिका 4

मुसहर समुदाय का राज्यवार लिंगानुपात

	बिहार	झारखंड	उड़ीसा	त्रिपुरा	उत्तर प्रदेश	उत्तराखंड	बंगाल	भारत
मुसहर लिंगानुपात	936	936	200	786	932	822	955	936
मुसहर लिंगानुपात	940	917	941	962	918	775	966	938
मुसहर लिंगानुपात	936	949	541	837	932	809	957	936
सम्पूर्ण लिंगानुपात	921	949	989	960	918	1000	953	949

स्रोत : हैंडबुक ऑफ सोशल वेलफेयर स्टेटिस्टिक्स 2021, सामाजिक न्याय मंत्रालय, भारत सरकार पृष्ठ : 13, 115-168 व 169-222 तक उपलब्ध आवश्यक प्रदत्तों की सहायता से एम.एस. एक्सेल-2021 सॉफ्टवेयर का उपयोग करके शोधार्थी द्वारा निर्मित

तालिका 4 के अवलोकन से स्पष्ट है कि भारत के ग्रामीण (949), शहरी (929) और सम्पूर्ण (943) लिंगानुपात के सापेक्ष मुसहर समुदाय का लिंगानुपात क्रमश: ग्रामीण (936), शहरी (938) और सम्पूर्ण (936) है; जोकि राष्ट्रीय लिंगानुपात की तुलना में ग्रामीण और सम्पूर्ण स्तर पर कम है जबकि शहरी स्तर पर अधिक है। राज्यों की बात करें तो बिहार, उत्तर प्रदेश और पश्चिम बंगाल में ग्रामीण, शहरी और सम्पूर्ण स्तर पर मुसहर समुदाय का लिंगानुपात राज्य के लिंगानुपात से अधिक है। उत्तराखण्ड में ग्रामीण, शहरी और सम्पूर्ण स्तर पर मुसहर समुदाय का लिंगानुपात राज्य के लिंगानुपात से कम है। उड़ीसा और त्रिपुरा में ग्रामीण और सम्पूर्ण स्तर पर मुसहर समुदाय का लिंगानुपात राज्य के लिंगानुपात से कम है जबकि शहरी स्तर पर अधिक। मुसहर समुदाय की सम्पूर्ण स्तर पर राज्यवार लिंगानुपात का ट्रेंड लाइन देखने से स्पष्ट है कि मुसहर समुदाय का लिंगानुपात राज्य के सम्पूर्ण स्तर के लिंगानुपात के आस-पास ही है। R^2 का मान 0.0378 है। इससे पता चलता है कि मुसहर समुदाय का लिंगानुपात और संबंधित राज्यों के लिंगानुपात में अधिक विचलन नहीं है।

मुसहर समुदाय का सामाजिक-आर्थिक परिदृश्य

मुसहर समुदाय की सामाजिक-आर्थिक स्थिति अन्य अनुसूचित जातियों की तुलना में आज भी बहुत निम्नतर स्तर की है। मुसहर समुदाय अपने आस-पास के परिवेश में रहने वाले अन्य समुदायों से कटकर रहता है। अक्सर यह देखा जाता है कि मुसहर समुदाय गाँव के किनारे मुख्य समाज से अलग निवास करता है। मुसहर समुदाय हाशिए पर रहता है। मुख्य समाज के विभिन्न सामाजिक क्रिया-कलापों, रीति-रिवाजों से हटकर मुसहर समुदाय अपने विशिष्ट क्रिया-कलापों एवं रीति-रिवाजों के साथ जीवन यापन करता है। कुमार (2006) ने मुसहरों की दयनीय सामाजिक स्थिति का विश्लेषण करते हुये बताया है कि 'स्थानीय अभिजात वर्ग और पूर्व जमींदारों के नेतृत्व में राज्य संचालित विकास प्रतिमानों की भूमिका, मुसहरों की दयनीय अवस्था के लिए अधिक जिम्मेदार रही है। अभिजात वर्ग ने दलितों को और अधिक दलित बनाने का काम किया है। इसे स्पष्ट रूप से उजागर करने की आवश्यकता है, क्योंकि दलित समूह की कुछ एक जातियों को छोड़ दिया जाए तो शेष का हाल और बुरा होता जा रहा है। मुसहरों की स्थिति अभिजात वर्ग और जमींदारों की व्यवस्था के कारण बंधुआ मजदूर जैसी ही बनी हुई है। उनकी सामाजिक-आर्थिक स्थिति में कुछ विशेष परिवर्तन नहीं हुआ है तथा वे आज भी दलितों के बीच में दलित होकर जीवन निर्वहन करने हेतु मजबूर हो रहे हैं'। फिर भी आजादी के बाद विकास कार्यक्रमों का अवलोकन करने पर ज्ञात होता है कि मुसहरों के लिए केंद्र एवं राज्य सरकारों, सामाजिक कार्यकर्ताओं, विभिन्न संगठनों तथा गैर-सरकारी संगठनों द्वारा चलाए जा रहे विभिन्न सामाजिक कार्यक्रम एवं योजनाएँ मुसहरों की सामाजिक अस्मिता को सकारात्मक रूप से प्रभावित कर रही हैं। मुसहर समुदाय भी धीरे-धीरे अपनी सीमांतता की सीमाओं को पार करते हुए लाभ के विविध क्रिया-कलापों में प्रतिभाग कर रहा है। इसके परिणामस्वरूप उनकी सीमांतता की धारणा बदल बदल रही है (सिंह,

2013)। हालांकि इस बदलाव की गति बहुत धीमी है। विभिन्न सरकारी संस्थानों द्वारा किए जा रहे प्रयासों का मुसहरों के जीवन पर सार्थक प्रभाव पड़ रहा है। उनके साथ राज्य न केवल एक प्रमुख संवाद एजेंसी के रूप में कार्य कर रहा है बल्कि उनकी आर्थिक स्थिति और सामाजिक परिस्थिति को बदलने में महत्वपूर्ण भूमिका का निर्वहन भी कर रहा है (मुकुल,1999)।

भोजन, स्वास्थ्य और लैंगिक तटस्थता

मुसहर समुदाय की बहुत अधिक पिछड़ी सामाजिक-आर्थिक स्थिति के कारण उनका जीवन-यापन अत्यधिक निम्नतर स्तर का होता है। वे सामूहिक रूप से अपने सामाजिक समूह में जीवन निर्वहन करते हैं। उनकी सामूहिक एकता बहुत ही कमाल की होती है। वे अपने समुदाय की पहचान से खुद को रूबरू कराने में जरा भी संकोच नहीं करते हैं। उनका जीवन सुबह से शाम तक के व्यस्ततम मजदूरी वाले कार्यक्रमों में बंटा रहता है। उन्हें न्यूनतम आवश्यक पौष्टिक भोजन की भी आपूर्ति नहीं हो पाती है। कभी-कभी फाँका पर ही दिन काटना पड़ता है। हालांकि कोविड-19 के दौरान शुरू की गई प्रधानमंत्री गरीब कल्याण अन्न योजना से मुसहर समुदाय को खाद्यान्न उपलब्धता में विशेष फायदा हुआ है। लेकिन वर्तमान कमरतोड़ महंगाई के दौर में जब सामान्य नौकरी वालों का हाल बहुत ख़स्ता होता जा रहा है तो मुसहर समुदाय के दैनिक जीवन निर्वहन विवशता को देख-समझकर केवल रोना ही आता है। उनकी वास्तविक दैनिक स्थिति को शब्दों में अभिव्यक्त करना बहुत ही मुश्किल है। उनकी थाली में कभी भी सामान्य थाली का भोजन, जैसे- दाल, चावल, रोटी, सब्जी इत्यादि भी एक साथ नहीं मिलता है।

पोखरल (2020) के अनुसार 'मुसहर समुदाय के अधिकांश लोग एक साथ चावल दाल और सब्जी नहीं पकाते हैं। यदि वे दाल बनाते हैं तो सब्जी नहीं बनाते। इसका कारण पूछने पर वे लोग बताते हैं कि हमारे पास इतना समय नहीं होता है और न ही इतनी व्यवस्था होती है कि हम एक साथ दाल और सब्जी दोनों बना सकें'। मुसहर समुदाय का स्वास्थ्य सामान्यत: ठीक रहता है। वे जल्दी बीमार नहीं पड़ते हैं। क्योंकि वे जीतोड़ मेहनत करते हैं और उनके शरीर में स्फूर्ति बनी रहती है। लेकिन सामान्य लोगों की तुलना में स्वास्थ्यगत सुविधाओं तक उनकी पहुँच कमतर है। ऐसा देखा जाता है कि वे अपने स्वास्थ्य के प्रति उतने सजग नहीं रहते, जितना कि अन्य लोग सजग दिखायी पड़ते हैं। सरकार द्वारा ग्रामीण क्षेत्रों में प्राथमिक स्वास्थ्य केंद्र, आशा बहू, आंगनबाड़ी केंद्र इत्यादि के माध्यम से मूलभूत स्वास्थ्यगत सुविधाओं और संसाधनों तक सभी की पहुँच सुनिश्चित की जा रही है। हर घर शौचालय योजना के अंतर्गत शौचालय बनाने हेतु 12 हजार रुपये (छ:-छ: हजार की दो किस्त में) की आर्थिक सहायता भी सरकार द्वारा प्रदान की जा रहा है। इससे ग्रामीण मुसहर बस्तियों में भी शौचालय बने हैं। लेकिन सहायता राशि के कम होने के कारण ठीक से निर्माण न होना और नियमित रख-रखाव न होने के कारण उपयोग लायक नहीं बचे हैं। मुसहर समुदाय खुले में शौच करना अधिक पसंद करता है। इसमें उनकी स्वास्थ्यगत जागरूकता की कमी और खुले

में शौच से होने वाली स्वास्थ्यगत और पर्यावरणीय नुकसान की जानकारी का अभाव सहयोग करता है। अभी भी 38.5 प्रतिशत मुसहर समुदाय खुले में शौच कर रहे हैं। जिसे सख्ती से प्रतिबंधित किया जाना चाहिए क्योंकि यह स्वास्थ्य और पर्यावरण के लिए खतरनाक है (पौडेल एंड कट्टेल, 2019)। 'मुसहर, बच्चों का जन्म, ईश्वर की इच्छा और आशीर्वाद का प्रतीक मानते हैं। लड़की या लड़का होने से उन्हें कोई विशेष फर्क नहीं पड़ता। मुसहर समुदाय में लैंगिक भेदभाव नगण्य होता है' (पोखरेल, 2020)। मुसहर समुदाय में लैंगिक भेदभाव बहुत ही कम मात्रा में पाया जाता है। मुसहर अपनी संतान को पुरुष और महिला की नजर से नहीं देखते हैं। वे अपने बच्चों के लिंग के प्रति चयनात्मक भी नहीं होते हैं। उनके लिए बच्चे बड़े होकर काम में मदद करने वाले सहयोगी के रूप में होते हैं। उन्हें इस बात से भी कोई फर्क नहीं पड़ता है कि उनकी दो या तीन या उससे भी अधिक संताने केवल बालिका या केवल बालक हैं। उन्हें इस बात से भी कोई फर्क नहीं पड़ता है कि उनके पास कोई बेटा क्यों नहीं है। वे अपने बच्चों के साथ खुशी-खुशी अपना दुख-दर्द साझा करते हैं। मुसहर समुदाय में व्यवस्था और प्रेमविवाह दोनों की धारणा है। मुसहर अपने जीवन को बहुत खुले अंदाज में जीना पसंद करते हैं। उन्हें कल के लिए बहुत चिंता नहीं होती है। वे आज और अभी में जीना पसंद करते हैं। लेकिन वे अपने बच्चों की शिक्षा के प्रति उतने जागरूक नहीं हैं, जितना कि होना चाहिए। इसीलिए उनके समुदाय में औपचारिक शिक्षा के प्रति रुझान भी बहुत ही कम है। उनकी स्वास्थगत स्थिति भी बहुत खराब है। वे बच्चों को टीका लगवाने से भी डरते हैं, कतराते हैं। 'मुसहर समुदाय में लिंगानुपात की स्थिति ठीक है परन्तु साक्षरता दर अत्यंत निम्न स्तर का है। इस समुदाय का उच्च शिक्षा में पूर्णत: अभाव है' (कुमारी, 2020)। मुसहर समुदाय में महिला एवं पुरुष साथ-साथ रहते हैं, साथ-साथ बाजार जाते हैं, साथ-साथ काम पर भी जाते हैं। लेकिन घर के काम में पुरुष बहुत कम हाथ बटाते हैं। रसोई के काम तो महिलाओं के लिए अनिवार्य है। मुसहर महिलाओं का जीवन लैंगिक तथा जाति आधारित पहचान के आधार पर व्यतीत होता है (चन्द एंड बनर्जी, 2019)। जिस तरह से मुसहर समाज सामाजिक रूप से दबा कुचला है, उसी तरह से मुसहर जाति की महिलाएँ भी मुसहर समुदाय में दबी कुचली हैं और शक्ति-संबंधों के निर्धारण में या शक्ति के निर्धारण में उनके साथ महिला होने के नाते भेदभाव किया जाता है। मुसहर महिलाओं की स्थिति समाज और उनके घर दोनों जगह बहुत ही कमजोर है। क्योंकि समाज में वो बंधुआ मजदूर की तरह काम तो कर ही रही हैं साथ ही साथ घर में भी लगभग सभी काम उन्हीं के जिम्मे होता है। बच्चों की देखभाल, कपड़े धोना, खाना पकाना, पुरुष की सेवा करना तथा रोजी-रोटी की भी व्यवस्था करना जैसे दिन-प्रतिदिन के संघर्ष उनके दैनिक जीवन संसार का अभिन्न हिस्सा होते हैं। मुसहर औरतें गरीबी और बदहाली में अपने जीवन को व्यतीत करने के लिए मजबूर होती हैं (चाँद एवं बनर्जी, 2019)।

मुसहर समुदाय की आजीविका और रहन-सहन

अधिकांश मुसहर कृषि और तत्संबंधित क्षेत्रों में सबसे निचले स्तर पर मजदूर का काम करते हैं। मनरेगा के तहत भी उन्हें कुछ काम मिल जाता है। वे मौसमी बेरोजगारी के शिकार होकर जीवन व्यतीत करते हैं। ग्रामीण क्षेत्रों में मनरेगा, मजदूरी कार्य, बंधुआ मजदूरी इत्यादि के माध्यम से अपना जीवन-यापन करते हैं। 'बंधुआ मजदूरों को तो खाने-पीने की वस्तुएँ, पहनने हेतु साफ-स्वच्छ कपड़े, उचित आराम एवं चिकित्सकीय सुविधा भी ठीक से प्राप्त नहीं होती है। बालिकाओं-महिलाओं के साथ लैंगिक गाली-गलौज एवं यौन अपराध जैसी प्रताड़ना आम बात है। बंधुआ मजदूरी प्रतिबन्धित होने के बावजूद भी जारी है' (गिरि, 2012)। सामाजिक दृष्टिकोण से, स्वच्छ पेयजल और खाना पकाने के लिए उपयोग किये जाने वाले स्वच्छ ईन्धन तक उनकी पहुँच सीमित है। मुसहर मूल रूप से कृषि दैनिक मजदूरी करने वाले मजदूर हैं। मुसहर समुदाय अपनी आजीविका हेतु कृषि श्रमिक (28 प्रतिशत), दैनिक मजदूरी (42 प्रतिशत), व्यापार (14 प्रतिशत), विदेशी प्रेषण (8 प्रतिशत) और ड्राइवर (8 प्रतिशत) जैसे पेशों में शामिल है। 'बिहार में पुरुष मुसहर कृषि मजदूरी में 76.22 प्रतिशत तथा महिला मुसहर 68.00 प्रतिशत लगी हुई हैं। केवल 19.83 प्रतिशत घरों में पीने का पानी, बिजली और शौचालय की सुविधा उपलब्ध है। 56 प्रतिशत मुसहर आज भी गरीबी रेखा से नीचे जीवन-यापन करने के लिए मजबूर हैं। प्राचीन काल से उन्होंने अपने स्वयं के रीति-रिवाजों, कलाओं, आचार-विचारों, विश्वासों और सामाजिक-आर्थिक संस्थाओं का विकास किया है' (राणा, 2017)। अब मुसहर अपने स्वयं के त्योहारों जैसे 'फल्गु' और 'शंक्रान्तियों' के बजाय दाहिन और तेहर जैसे हिंदू त्योहारों को अधिक प्राथमिकता देते हैं। मुसहरों का ग्राम देवताओं की पूजा करने का तरीका, आत्माओं में विश्वास, विशिष्ट पोशाक पैटर्न और समूह प्रकार की बस्तियों का पैटर्न अन्य जातीय समूहों से अलग है (प्रसाद, 2007)। मुसहर समुदाय के किसी भी एक परिवार का पंजीकृत भूमि पर कब्जा नहीं है। वे पूर्णत: सरकारी या पट्टे की जमीन पर झोपड़ी बनाकर रहते हैं। 'विभिन्न आजीविका संसाधन जैसे कृषि, जल, वन और सार्वजनिक स्वास्थ्य तथा बस्तियाँ जलवायु परिवर्तन के प्रति संवेदनशील होते हैं (शर्मा, 2010)'। औसत तापमान में वृद्धि, बाढ़, शीत लहर, बीमारी, पशुधन रोग आदि के रूप में आजीविका के विभिन्न पहलुओं के लिए मुसहर समुदाय की आजीविका में और अधिक चुनौती पैदा कर रहे हैं। ग्रीन हाउस गैसों का उत्पादन बढ़ने से जलवायु परिवर्तन के विभिन्न परिणाम उन संसाधनों पर दबाव डाल रहे हैं, जिन पर गरीब लोग अपनी आजीविका के लिए अधिक निर्भर हैं। इससे अन्य समुदायों के साथ ही मुसहर समुदाय की दिनचर्या, रहन-सहन और आजीविका भी प्रभावित हो रही है। इसके अतिरिक्त प्राकृतिक संसाधनों तक पहुँच बाधित होना और अवसर की उपलब्धता की कमी भी मुसहर समुदाय की आजीविका को बुरी तरह से प्रभावित कर रहा है। 'मुसहरों के पास अधिकांश स्रोतों तक पहुँच नहीं के बराबर है और उनके पास स्रोतों तक पहुँच के पर्याप्त अवसर भी नहीं है। भूमि, पानी, पालतू जानवर, अच्छी मजदूरी वाले काम इत्यादि तक उनकी पहुँच आसान नहीं है' (थॉमस

एंड आरा, 2018)। दूसरी बात यह है कि वे सभी सरकारी योजनाओं का लाभ लेने वाले पात्रों की सूची में सबसे अन्त में होते हैं। क्योंकि पंचायती राज संस्थान की सबसे निचली इकाई ग्राम सभा में भी उनकी पहुँच ना के बराबर है। इसलिए उनसे संबंधित विभिन्न प्रकार के सरकारी योजनाओं का लाभ भी उन तक सबसे अंत में और सबसे कम मात्रा में पहुँच पाता है। विकास एजेंसियों और संसाधनों के बढ़ते प्रवाह के बावजूद, समुदाय की आजीविका पर अभी भी सीमित प्रभाव ही पड़ रहा है। अत: मुसहर समुदाय की बेहतरी हेतु आवश्यक है कि विभिन्न प्रकार के चलाए जा रहे सरकारी कार्यक्रमों जैसे - मनरेगा, सार्वजनिक वितरण प्रणाली, राष्ट्रीय ग्रामीण स्वास्थ्य मिशन इत्यादि में भ्रष्टाचार को समाप्त करके उसका क्रियान्वयन सही तरीके से किया जाये। उनके लिए शिक्षा और जागरूकता कार्यक्रम की विशेष आवश्यकता है। सामुदायिक सौहार्द, समरसता और समता को बढ़ावा दिया जाना चाहिए। अन्य जातियों और समुदायों को आगे बढ़कर मुसहर समुदाय को मुख्य समाज में शामिल करने की कोशिश करनी चाहिए। 'मुसहर समुदाय की आजीविका सुरक्षा को बढ़ाने के लिए लक्षित हस्तक्षेपों का जवाब देने के लिए एक मजबूत संस्थागत आधार के साथ-साथ सामुदायिक तैयारी भी आवश्यक है (पौडेल एंव अन्य, 2023)।

शैक्षिक निहितार्थ

- भारतीय संविधान के अनुच्छेद -341 और 342 के प्रावधानों के अनुसार अनुसूचित जाति और अनुसूचित जनजाति वर्ग की सूची में किसी भी राज्य/केंद्र शासित प्रदेश की किसी भी जाति/वर्ग को सम्मिलित करने और सूची से बाहर करने की शक्ति केवल राष्ट्रपति को दिया गया है। मुसहर समुदाय को उत्तर प्रदेश में अनुसूचित जाति वर्ग में रखा गया है। मुसहर समुदाय की अत्यधिक पिछड़ी सामाजिक-आर्थिक स्थिति और मुख्य समाज से अलगाव को ध्यान में रखते हुये उन्हें अनुसूचित जनजाति वर्ग में रखा जाना चाहिए। ताकि उन पर सरकारों का विशेष ध्यान जाये और उनके लिए विशेष प्रयास किए जा सकें।
- वर्तमान समय में मुसहर समुदाय अनुसूचित जाति वर्ग में सामाजिक-आर्थिक आधार पर सबसे अधिक पिछड़े हुये हैं। अपनी विशिष्ट सामाजिक-सांस्कृतिक विशेषता के कारण वे मुख्यधारा के समाज से भी कटे हुए हैं। उनका सामाजिक-आर्थिक विकास बहुत धीमी गति से हो रहा है। इसलिए सरकार और गैर सरकारी संगठनों द्वारा मुसहर समुदाय के लिए जमीनी स्तर पर विशेष प्रावधान किया जाना चाहिए है। ताकि मात्रात्मक आंकड़ों के साथ-साथ उनके जीवन में गुणात्मक परिमार्जन सुनिश्चित हो सके।
- मुसहर समुदाय के साथ सामाजिक-आर्थिक स्तर पर तो भेदभाव सामान्य बात है। महत्त्वपूर्ण बात यह है कि उनके सामाजिक-आर्थिक पिछड़ेपन का फायदा उठाकर सरकारी योजनाओं, कार्यक्रमों और नीतियों के क्रियान्वयन में भी भेदभाव किया

जाता है। चूंकि उनकी स्थिति समाज के आख़िरी पायदान पर है और वे रहते भी मुख्य समाज से अलग हैं, इसलिए सरकारी योजनाएँ और सरकारी प्रयास उन तक सबसे आखिर में ही बचे-खुचे स्वरूप में पहुँचते हैं। अत: सुझाव है कि सरकारी योजनाओं, नियमों-कानूनों का कड़ाई से समयबद्ध पालन अनिवार्य होना चाहिए।

- मुसहर समुदाय सबसे अधिक अभावों वाला समुदाय है और उनके लिए रोटी, कपड़ा, मकान, शिक्षा, रोजगार और सामाजिक समावेशन की आवश्यकता भी सबसे अधिक है। अत: मुसहर समुदाय तक सभी सरकारी योजनाओं-प्रयासों की पहुँच समुचित मात्रा में और सबसे पहले होनी चाहिए।
- मुसहर समुदाय तक सरकारी योजनाओं-प्रयासों की पहुँच सुनिश्चित करने हेतु यह आवश्यक है कि लोक प्रशासन की ऊपर से नीचे (राज्य, मण्डल, जिला, तहसील, विकासखंड होते हुये गाँव) तक की मशीनरी और पंचायती राज की सबसे निचली इकाई अर्थात ग्राम पंचायत की कार्य-प्रणाली का मूल मंत्र 'सबसे अधिक जरूरतमन्द- सबसे पहले लाभान्वित हो' होना चाहिए। यह रणनीति केवल फाइलों में न होकर वास्तविक जमीनी क्रियान्वयन में होनी चाहिए।
- मुसहर समुदाय ग्रामीण और शहरी दोनों परितंत्र में मुख्य-धारा वाले समाज से कटा हुआ है। इसलिए मुसहर समुदाय के साथ सामाजिक स्तर पर बहुत अधिक भेदभाव किया जाता है। उन्हें मुख्य समाज में सम्मिलित करने हेतु केवल सरकारी प्रयास पर्याप्त नहीं होंगे। मुसहर समुदाय को मुख्य समाज में लाने हेतु मुख्य समाज को अपनी सामंती सोच, जातीय जकड़न, धन-सम्पदा-पद की श्रेष्ठता इत्यादि को त्यागकर मुसहर समुदाय के साथ भी आत्मीय बर्ताव करते हुये समुदाय को भी मुख्य समाज का हिस्सा बनाकर सामाजिक समरसता और सद्भाव का निर्माण करना चाहिए।
- मुसहर समुदाय तक स्थायी आवास, नि:शुल्क शिक्षा, कौशल, खेल, नियमित रोजगार और बेहतर स्वास्थ्यगत सुविधाओं की पहुँच सुनिश्चित की जानी चाहिए। ताकि वे भी अपनी मूलभूत जरूरतों को पूर्ण करते हुये अपनी कर्मठता, ईमानदारी और जुझारूपन का उपयोग कर देश की तरक्की में अपना पूर्ण योगदान कर सकें।
- मुसहर समुदाय की जीवन दशा को सुधारने हेतु राष्ट्रीय और राज्य स्तर एक विशिष्ट शोध सेल का निर्माण किया जाना चाहिए। यह शोध सेल समय-समय पर नियमित रूप से मुसहर समुदाय की वास्तविक जमीनी हक़ीक़त को शोध रिपोर्ट के रूप में सरकारों के समक्ष प्रस्तुत करे ताकि रिपोर्ट के आधार पर मुसहर समुदाय हेतु विशिष्ट नीति का निर्माण और समुचित क्रियान्वयन करके मुसहर समुदाय का सामाजिक-आर्थिक विकास सुनिश्चित किया जा सके।

निष्कर्ष

निष्कर्षत: यह कहा जा सकता है कि मुसहर समुदाय मूल रूप से तटीय और जंगली इलाकों में निवास करता था। वे जंगल में पैदा होने वाले फल-फूल, लकड़ी, मांस इत्यादि पर निर्भर थे। लेकिन धीरे-धीरे वे भूमिहीन और जंगल विहीन होते गए और अपने अस्तित्व को बनाए रखने हेतु मजदूर बन गए। वर्तमान समय में मुसहर समुदाय अपने सामाजिक-आर्थिक पिछड़ेपन के कारण अनुसूचित जातिवर्ग के सबसे निचले पायदान पर मुख्य समाज से कटकर जीवन-यापन कर रहा है। मुसहर समुदाय भूत-प्रेत, झाड़-फूंक और टोना-टोटका जैसे अंधविश्वासी उपचारों पर आज भी निर्भर है। लेकिन जैसे-जैसे प्राथमिक स्वास्थ्य सुविधाओं का ग्रामीण क्षेत्रों में सामान्य लोगों तक पहुँच बढ़ रही है वैसे-वैसे इसका सार्थक प्रभाव उनके स्वास्थ्य पर भी पड़ रहा है। सीमित आवश्यकताओं के साथ वे अपना जीवन जीने के लिए मजबूर थे, लेकिन अब विभिन्न सरकारी योजनाओं यथा- मनरेगा, प्रधानमंत्री आवास योजना, हर घर जल योजना जैसे कार्यक्रमों की पहुँच सुदूर बस्तियों तक होने के कारण उनका जीवन स्तर, खान-पान, रहन-सहन इत्यादि में सुधार हो रहा है। मुर्गी पालन, सुअर पालन, पत्तल और दोना बनाना, लकड़ी काटना, खेतों-भट्ठों पर मजदूरी करना, ट्रैक्टर चलाना इत्यादि उनके आजीविका के महत्त्वपूर्ण साधन हैं हालांकि मुसहर समुदाय तक रोटी, कपड़ा, आवास, शिक्षा, कौशल, रोजगार और सामाजिक समावेशन तथा सामाजिक समरसता-सद्भाव की समुचित पहुँच आज भी नहीं है। मुसहर समुदाय की सामाजिक-आर्थिक और आजीविका संबंधित न्यूनतम आवश्यकताओं तक की पूर्ति हेतु सरकारी और गैर-सरकारी योजनाओं-कार्यक्रमों के साथ ही साथ सामाजिक समानता के स्तर पर लाने के लिए उनके साथ हो रहे भेदभाव को दूर करने के लिए मुख्य समाज को स्वयं प्रेरित होकर आगे आना होगा। तभी सामाजिक अलगाव की खाई पाटी जा सकेगी और सामाजिक अलगाव की खाई पाटे बिना मुसहर समुदाय का मुख्य समाज में समावेशन नहीं हो सकेगा। बिना सामाजिक समावेशन के सरकारी प्रयास होने के बावजूद मुसहर समुदाय का लक्ष्यित विकास संभव नहीं है।

सन्दर्भ

चन्द, डी. एंड बनर्जी, एस. (2019). 'एक्सप्लोरिंग द इंटरसेक्शन ऑफ जेंडर, कास्ट एंड स्पेस इन द लाइफवर्ल्ड ऑफ मुसहर विमेन इन उत्तर प्रदेश'. *साउथ एशियन जर्नल ऑफ पार्टिसिपेटिव डेवलपमेंट,* 19(1), 7-27. https://www.researchgate.net/profile/Dinesh-Chand-2/publication/344253018_Exploring_the_Intersections_of_Gender_Caste_and_Space_in_the_Lifeworld_of_Musahar_Women_in_Uttar_Pradesh/links/6005d251299bf14088a5fb3f/Exploring-the-Intersections-of-Gender-Caste-and-Space-in-the-Lifeworld-of-Musahar-Women-in-Uttar-Pradesh.pdf

गिरि, बी.आर. (2012). 'द ब्रांडेड लेबर सिस्टम इन नेपाल मुसहर एंड तारों कम्युनिटीज असेसमेंट ऑफ द हालिया एंड कमैया लेबर कॉन्ट्रैक्ट'. *जर्नल ऑफ अल्टरनेटिव पर्सपेक्टिव्स इन द सोशल साइंस,* 4(2), 518-551. Retrieved from: https://www.academia.edu/4236358/The_Bonded_

Labour_System_in_Nepal_Musahar_and_Tharu_Communities_Assessments_of_the_Haliya_and_Kamaiya_Labour_Contracts

कुमार, ए. (2006). 'कल्चर, डेवलपमेंट एंड द कल्चरल कैपिटल ऑफ फार्स : द मुसहर कम्युनिटी इन बिहार'. *इकोनॉमिक एंड पॉलिटिकली वीकली,* 41(40), 4281-4291 http://www.jstor.org/stable/4418787

कुमार, धर्मेंद्र (2017). मैपिंग मार्जिनलाइजेशन ऑफ कॉस्ट एंड इनक्लूसन ऑफ कॉस्ट : अ स्टडी ऑफ मानपुर विलेज, गया (बिहार). अप्रकाशित एम.फिल. थेसिस, सेंटर फॉर द स्टडी ऑफ सोशल एक्सक्लूशन एंड इंक्लूसिव पॉलिसी, हैदराबाद विश्वविद्यालय.

मुकुल (1999). 'द अनटचेबल प्रेजेंट : एवरीडे लाइफ ऑफ मुसहरस इन नार्थ बिहार'. *इकोनॉमिक एंड पोलिटिकल वीकली,* 34(49), 3465-3470. http://www.jstor.org/stable/4408689

नारायण, बदरी (2018). *खंडित आख्यान : भारतीय जनतंत्र में अदृश्य लोग,* आक्सफोर्ड युनिवर्सिटी प्रेस, नई दिल्ली.

पोखरेल, बी. (2020). 'स्त्रैनेड आइडेंटिटी : कल्चरल एंड रिलीजियस रीचुअल्स ऑफ अ मुसहर कम्युनिटी'. *सोशल इन्क्वायरी : जर्नल ऑफ सोशल साइंस रिसर्च,* 2(1), 128-150. https://doi.org/10.3126/sijssr.v2i1.28912

पौडेल, कृष्णा, अधिकारी, देवेंद्र एंड पौडेल, शारदा (2023). रेफ्रेमिंग लाइवलीहुडस स्ट्रेटेजीज : मुसहर चेंजिंग लाइवलीहुडस कॉन्टेक्ट्स एंड देयर रेस्पॉन्सेस टू डायवरस डेवलपमेंट इंटरवेंशंस. https://www.researchgate.net/publication/267370210_Reframing_Livelihoods_Strategies_MusaharBote's_Changing_Livelihoods_Contexts_and_their_Responses_to_Diverse_Development_Interventions

पौडेल एंड कट्टेल (2019). 'सोशल चेन्जेस इन मुसहर कम्युनिटी : ए केस स्टडी ऑफ धनुसा डिस्ट्रिक्ट ऑफ नेपाल'. *नेपाल जर्नल ऑफ मल्टीडिसीपलीनरी रिसर्च,* 2(4), 9-16 https://doi.org/10.3126/njmr.v2i4.28703

प्रसाद, ए. (2007). 'द मुसहर्स ऑफ बिहार : ए दलित कम्युनिटी इन द वारटेक्स ऑफ चेंज'. *द इंडियन जर्नल ऑफ सोशल वर्क,* 68(1), 152-167. https://ijsw.tiss.edu/tmp/exported_Ijsw1940-2014/collect/ijsw/index/assoc/HASH632f/afdd2347.dir/doc.pdf

प्रसाद, डी. एवं कुमार, ए. (2018). 'गुलामगिरी एंड कॉस्ट टुडे : एन इंटरप्रिटेशन'. *इन्टरनेशनल जर्नल ऑफ रिसर्च एंड एनालिटिकल रिव्यु,* 5(3), पृ. 129-132

प्रसाद, डी. एवं श्रीहरी, जी. (2017). 'मैपिंग द पॉलिटिक्स ऑफ शौचालय इन दलित लोकलिटीज : एन इन्क्वायरी', *कन्टेम्पेरी वॉइस ऑफ दलित,* 9(1), पृ. 225-271.

राणा, एम.के. (2017). ऑकुपेशन एंड एजुकेशनल स्टेटस ऑफ मुसहर : ए स्टडी ऑफ बारदीबास म्यूनिसिपैलिटी महोत्तरी, नेपाल. ऑनलाइन प्रकाशित शोध प्रबंध, सेंट्रल डिपार्टमेंट ऑफ रुरल डेवलपमेंट, त्रिभुवन यूनिवर्सिटी कृतिपुर काठमांडू, नेपाल. Retrieved from: https://elibrary.tucl.edu.np/handle/123456789/2329

शर्मा, एस. (2010). क्लाइमेट चेंज इम्पैक्ट ऑन लाइवलीहुड एंड वलनरबिलिटी: ए केस स्टडी ऑफ मुसहर कम्यूनिटी इन सप्तरी डिस्ट्रिक्ट इन नेपाल. ऑनलाइन प्रकाशित शोध प्रबंध, बीआरएसी यूनिवर्सिटी ढाका, बांग्लादेश. Retrieved from: http://dspace.bracu.ac.bd/xmlui/handle/10361/1396

शर्मा, जोखन एंड नायक, जे.के. (2018). 'मुसहर शैडयूल्ड कास्ट इन सोशल ट्रांजिशन फेज : एन अंथ्रोपोलोजिकल स्टडी'. *एशियन मैं (द) - एन इंटरनेशनल जर्नल,* 12(2), 266-273. https://www.researchgate.net/publication/330562134_Musahar_Scheduled_Caste_in_Social_Transition_Phase_An_Anthropological_Study

सामाजिक न्याय मंत्रालय, भारत सरकार (2021), *हैंडबुक ऑफ सोशल वेलफेयर स्टेटिस्टिक्स* (2021). पेज: 29 व 61-114. retrieved from: https://socialjustice.gov.in/writereaddata/UploadFile/HANDBOOKSocialWelfareStatistice2021.pdf(29/12/2022)

सिंह, एस.एस. (2013). 'इंटरवेंशन, आइडेंटिटी एंड मार्जिनलिटी : एन एथ्नोग्राफिक अकाउंट ऑफ द मुसहर्स'. *इकोनॉमिक एंड पोलिटिकल वीकली,* 48(20), 52-59. http://www.jstor.org/stable/23527368

थामस, एम.जे. एंड आरा, ए. (2018) इस सोशियो इकोनॉमिक अप्रेजल ऑन लाइवलीहुड स्ट्रगल ऑफ मुसहर कम्यूनिटी इन इलाहाबाद डिस्ट्रिक्ट, द ओरियंटल एंथ्रोपोलॉजिस्ट, *इंटरनेशनल जर्नल ऑफ द साइंस ऑफ मैन,* 18(1), 121-129. https://journals.sagepub.com/doi/10.1177/0976343020180109

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अन्वेषिका

राष्ट्रीय अध्यापक शिक्षा परिषद्
नई दिल्ली

अन्वेषिका

(अध्यापक शिक्षा की समकक्ष व्यक्ति समीक्षित शोध पत्रिका)

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परिचय एवं उद्देश्य

अन्वेषिका, राष्ट्रीय अध्यापक शिक्षा परिषद् (एनसीटीई-भारत सरकार का सांविधिक निकाय), नई दिल्ली द्वारा वर्ष में तीन बार, अर्थात अप्रैल, अगस्त तथा दिसंबर में प्रकाशित होने वाली हिंदी भाषा की एक समकक्ष व्यक्ति-समीक्षित राष्ट्रीय पत्रिका है। इस पत्रिका का उद्देश्य अध्यापक-शिक्षा के क्षेत्र में हितधारकों के मध्य वैचारिकी, शैक्षिक नीतियों व नवाचारों के संबंध में विचार-विनिमय व विमर्श हेतु एक मंच प्रदान करता है। यह क्षेत्रीय और वैश्विक स्तर पर अध्यापक शिक्षा के क्षेत्र में शिक्षा के बहु-विषयक, तुलनात्मक और व्यावहारिक विश्लेषण को प्रोत्साहित करती है। इन उद्देश्यों की पूर्ति हेतु, यह पत्रिका शिक्षकों और शिक्षक-प्रशिक्षकों के व्यावसायिक विकास, शिक्षा-कर्मियों के अनुभवजन्य लेखों तथा अध्यापक शिक्षा में नैतिक और गुणवत्तापूर्ण सरोकारों से संबंधित विभिन्न क्षेत्रों में ऐतिहासिक और समकालीन विषयों और चिन्ताओं पर चिंतनशील लेख, शोधपत्र, आलोचनात्मक समीक्षाएं, शिक्षा की अवधाराणाओं और सिद्धांतों का दार्शनिक विश्लेषण, पुस्तक समीक्षाएं और टिप्पणियाँ आमंत्रित करती है। मौलिक, अप्रकाशित, अकादमिक सत्यनिष्ठायुक्त तथा प्रस्तुतीकरण व नैतिक मानकों के अनुरूप लेखों की निष्पक्ष समीक्षा हेतु एक कठोर प्रक्रिया का पालन किया जाता है।

श्रीमती अभिलाषा झा मिश्र, सदस्य सचिव, राष्ट्रीय अध्यापक शिक्षा परिषद्, नई दिल्ली द्वारा प्रकाशित तथा दया प्रिंटर्स, कोटला मुबारकपुर द्वारा मुद्रित

अन्वेषिका

(अध्यापक शिक्षा की समकक्ष व्यक्ति समीक्षित शोध पत्रिका)
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सारांश

परिवर्तनशील शिक्षण-अधिगम प्रक्रिया के साथ ही आकलन संबंधी नई समस्याएँ, समाधान और संप्रत्यय भी पैदा हुए हैं। इस शोधपत्र का मुख्य सरोकार शैक्षिक आकलन से सम्बंधित प्रकाशित अनुसंधानों का ग्रंथमितीय विश्लेषण और वैज्ञानिक दृश्यीकरण करना था, जिसके अंतर्गत इस संदर्भ से जुड़ा सर्वाधिक अनुसन्धान प्रकाशित करनेवाला देश, सर्वाधिक उद्धरणों (साईटेशन) वाले शोधकर्ता, लोकप्रिय मुख्य शब्द (ट्रेंडिंग कीवर्ड्स) और सर्वाधिक अनुसंधान प्रकाशित करने वाली पत्रिकाओं (स्रोतों) का मात्रात्मक विश्लेषण और मैपिंग की गई है। इसके लिए लेखक द्वारा 'लेंस डेटाबेस' से शैक्षिक आकलन संबंधी 1451 प्रकाशनों (2010-2024 तक) का एमएस एक्सेल एवं वोसव्युवर सॉफ्टवेयर की सहायता से ग्रंथमितीय विश्लेषण किया गया है। विश्लेषणोपरांत प्राप्त हुआ कि शैक्षिक आकलन संबंधित सबसे अधिक प्रकाशन (136) वर्ष 2023 में तथा सबसे कम प्रकाशन (42) वर्ष 2012 में प्रकाशित हुए हैं। सर्वाधिक प्रकाशन (97%) शोध लेख के रूप में हुए हैं। कुल 435 और 409 प्रकाशनों के साथ सभी 61 देशों में संयुक्त राज्य अमेरिका (34%) और यूके (32%) क्रमशः प्रथम और द्वितीय स्थान पर शीर्ष देश हैं, जिन्होंने शैक्षिक आकलन पर अनुसन्धान पत्र प्रकाशित किए। कुल 5272 लेखकों के शैक्षिक आकलन संबंधित 1451 प्रकाशन 919 स्रोतों में प्रकाशित हुए हैं। उक्त प्रकाशनों में कुल 1395 अन्य मुख्य शब्द प्रयुक्त किए गए हैं। एजुकेशन और असेसमेंट शीर्ष मुख्य शब्द हैं। ब्रूखार्ट (2011) द्वारा लिखित 'एजुकेशनल असेसमेंट: नॉलेज एंड स्किल्स फॉर टीचर्स' सर्वश्रेष्ठ शोधपत्र है, जिसे कुल 275 उद्धरण प्राप्त हुए हैं। यह शोधपत्र वैश्विक वैज्ञानिक समुदाय के साथ-साथ शैक्षिक आकलन के क्षेत्र में शोध करने वाले नवीन शोधार्थियों के लिए भी बहुत उपयोगी होगा। इस शोधपत्र की सहायता से शिक्षण और अनुसंधान कार्य करने वाले लोग वैश्विक स्तर पर शैक्षिक आकलन के संबंध में अभी तक प्रकाशित श्रेष्ठतम शोध प्रकाशनों, स्रोतों और लेखकों तक आसानी से पहुँचकर आवश्यक शोध एवं अन्य कार्य उत्तम ढंग से सम्पन्न कर सकते हैं।

मुख्य शब्द: *शैक्षिक आकलन, ग्रंथमितीय विश्लेषण, वोसव्युवर सॉफ्टवेयर, नेटवर्क दृश्यीकरण और सघनता मानचित्रण।*

पृष्ठभूमि

आकलन, "जानकारी एकत्र करने के लिए एक व्यवस्थित प्रक्रिया है, जिसका उपयोग लोगों या वस्तुओं की विशेषताओं के बारे में अनुमान लगाने के लिए किया जा सकता है" (एरा,1999)। आकलन को साक्ष्य एकत्र करने और परिणामों से संबंधित निर्णय लेने की प्रक्रिया के रूप में जाना जाता है। ऑक्सफोर्ड शब्दकोश के अनुसार आकलन शब्द कॉमर्स और इकोनोमिक्स, जैसे विषयों में 15वीं शताब्दी के मध्य से प्रयुक्त होता रहा है, लेकिन शिक्षाशास्त्र विषय में यह 1950 से प्रयोग होना शुरु हुआ है। यह डेटा एकत्र करने और उन्हें एक व्याख्यात्मक रूप देने की प्रक्रिया है, जिसके आधार पर एक सारगर्भित निष्कर्ष तक पहुंचा जा सकता है। यदि कक्षागत आकलन की बात करें तो हम कह सकते हैं कि जब कोई शिक्षक कक्षा में शिक्षण-अधिगम की चलायमान प्रक्रिया के दौरान विद्यार्थियों की अधिगम प्रक्रिया का अवलोकन करता है, प्रत्येक विद्यार्थी की अधिगम स्थिति और प्रक्रिया संबंधी प्रतिक्रिया एकत्र करता है और अधिकतम अधिगम हेतु सुविधाएं प्रदान करने के लिए अपनी शिक्षण-अधिगम रणनीति में सुधार करता है, तो वह आकलन कर रहा है। 'अधिगम का आकलन, अधिगम के लिए आकलन और अधिगम के रूप में आकलन' के आधार पर आकलन की अवधारणा को तीन स्वरूप में स्पष्ट किया जाता है। वास्तव में कक्षागत आकलन के लिए बहुत अधिक निपुणता और धैर्य की जरूरत पड़ती है। आकलन के पहले दो स्वरूप में आकलनकर्त्ता के रूप में अध्यापक को अपनी भूमिका का निर्वहन करना पड़ता है, जबकि तीसरे स्वरूप, जिसे हम सभी 'अधिगम के रूप में आकलन' से जानते हैं; में विद्यार्थी स्वयं अपना आकलन करता है। इसे विशेष रूप से कनाडा और ऑस्ट्रेलिया के संदर्भ में, हेवर्ड (2015) द्वारा विद्यार्थियों के शैक्षिक प्रगति की देखरेख और निर्देशन में उनकी भूमिका को चित्रित करने के लिए अधिक सटीक तरीके से नियोजित किया गया था। प्रामाणिक कार्यों से छात्र-उपलब्धि संबंधी अनुमान प्राप्त करने हेतु आकलन के लिए पर्याप्त समय की आवश्यकता होती है (लिन, 1994)। यदि आकलन अभ्यासों में भाग लेकर भी विद्यार्थी सीखने संबंधी कोई विशेष लाभ प्राप्त नहीं कर रहे हैं, तब आकलन को तर्कसंगत बनाना चुनौतीपूर्ण हो जाता है एवं ऐसी स्थिति में रचनात्मक आकलन की भूमिका महत्त्वपूर्ण हो जाती है, जिसे बेनेट (2011) द्वारा भी स्वीकार किया गया है। 'सीखने के लिए आकलन' का उपयोग शिक्षक द्वारा अपनी निर्देशात्मक प्रविधियों को परिवर्तित करने के लिए किया जाता है, जबकि 'सीखने का आकलन' यह निर्धारित करता है कि विद्यार्थियों ने पूर्व-निर्धारित अधिगम उद्देश्यों के सापेक्ष कितना सीखा है। वस्तुतः शैक्षिक आकलन अपने समस्त स्वरूपों में विद्यार्थियों के अधिगम के संबंध में सारगर्भित अनुमान लगाने की एक प्रक्रिया है। विद्यार्थी, अधिगम क्रियाओं के साथ-साथ आकलन क्रियाओं में भी सक्रिय प्रतिभाग करते हैं, जिससे आकलन संबंधी प्रदत्त उत्पन्न होता है। शिक्षक उन प्रदत्तों का कई और विविध स्रोतों से संकलन करके विश्लेषणोपरांत सारगर्भित अनुमान का निर्माण करते हैं। अंत में उन अनुमानों की सहायता से अपनी शिक्षण कार्यनीति में आवश्यक परिमार्जन करके विद्यार्थियों को बेहतर अधिगम हेतु सुविधा प्रदान करते हैं।

साइंटोमेट्रिक्स को "वैज्ञानिक संचार और विज्ञान एवं प्रौद्योगिकी के मात्रात्मक पहलुओं का अध्ययन" के रूप में परिभाषित किया जा सकता है। यह विशेषतः कंप्यूटर भंडारण की बढ़ी हुई क्षमताओं और वैज्ञानिक संचार संबंधी सूचना की पुनर्प्राप्ति (यथा- उद्धरण विश्लेषण) से सम्बंधित है (लेडेसडॉर्फ, 2001)। ग्रंथमितीय विश्लेषण (साइंटोमेट्रिक या बिब्लियोमेट्रिक तकनीक) यथा, सह-उद्धरण विश्लेषण, सह-लेखकत्व विश्लेषण और ग्रंथ-सूची युग्मन में किसी वैज्ञानिक संप्रत्यय का संरचनात्मक प्रतिनिधित्व तैयार करने के लिए उससे संबंधित प्रकाशित डॉक्यूमेंट्स को किसी

डेटाबेस यथा- स्कोपस, डायमेंशन, लेंस, पबमेड, गूगल स्कालर, वेब ऑफ साइंस इत्यादि से ग्रंथ-सूची के रूप में लिया गया (एक्सट्रैक्टेड) डेटासेट का उपयोग करते हैं। वैज्ञानिक विश्लेषण की यह पद्धति विद्वानों को विषय विशेष में अनुसंधानरत शोधार्थियों द्वारा प्रयुक्त समेकित ग्रंथ- सूची को आधार बनाने में सक्षम बनाती है, जो उद्धरण के माध्यम से अपने दृष्टिकोण को स्पष्ट करते हैं। ग्रंथमितीय विश्लेषण का उपयोग तेजी से बढ़ रहा है (चेंग एट अल., 2023)। ग्रंथमितीय विश्लेषण एक उभरता हुआ क्षेत्र है, जिसमें विद्वानों के बीच अनुसंधान और विभिन्न चरों के अंतर्संबंधों की प्रगति को मौजूदा दस्तावेजों का उपयोग करके मात्रात्मक पद्धतियों के प्रयोग से सफलतापूर्वक चित्रित किया जाता है (वांग एट आल., 2021)। यह दृष्टिकोण प्रासंगिक विद्वानों के प्रकाशित साहित्य का विश्लेषण करके उसकी उत्पादकता और अंतरराष्ट्रीय सहयोग की जांच के लिए एक मजबूत रूपरेखा प्रदान करता है। ग्रंथमितीय विश्लेषण मात्रात्मक विश्लेषण पर आधारित, स्थापित और प्रभावी सांख्यिकीय पद्धति है, जो शोधकर्ताओं को वैश्विक दृष्टिकोण से समग्र परिप्रेक्ष्य का अनावरण करने की महत्त्वपूर्ण क्षमता प्रदान करती है (जिया एट अल., 2024)। ब्राडौस (1987) का मानना है कि साइंटोमेट्रिक्स को "मूर्त प्रकाशित संस्थाओं, ग्रंथ-सूची इकाइयों और/ या उनके संबंधित सरोगेट्स की मात्रात्मक विश्लेषण" के रूप में वर्णित किया जा सकता है। एक विश्लेषणात्मक उपकरण के रूप में, साइंटोमेट्रिक्स बौद्धिक, सामाजिक और वैचारिक ढांचे (जुपिक एंड केटर, 2015) के अनुसंधान परिणाम का विश्लेषण करता है, जिसमें खोजे गए विषयों, उपयोग की जाने वाली पद्धतियों, प्रयुक्त प्रतिचयन, पिछले विद्वानों के योगदान यथा: मोनोग्राफ, सम्मेलन की कार्यवाही और सहकर्मी-समीक्षा पत्रिकाओं का विश्लेषण सम्मिलित होता है (कोबो एट अल., 2011; मैकबर्नी और नोवाक, 2002)। बेंकेनड्वर्फ एवं जेहरर (2013) ने दो प्रकार की साइंटोमेट्रिक पद्धतियों: (1) मूल्यांकन तकनीक और (2) संबंधपरक तकनीक का वर्णन किया है, जो मूल्यांकन तकनीक उत्पादकता मेट्रिक्स, प्रभाव संकेतक और हाइब्रिड उपायों के प्रयोग पर बल देती है (हाल, 2011)। संबंधपरक तकनीक उद्धरणों, लेखकों, संबद्धताओं और खोज-शब्दों का विश्लेषण करके प्रकाशित शोधपत्रों के बीच अंतर्संबंधों की जांच करती है। इस तरह की पद्धतियां शोधकर्ताओं और पाठकों को विषयों के बौद्धिक प्रतिमानों, क्षेत्रों की सामाजिक संरचनाओं और नवीन अनुसंधान विषयों की उत्पत्ति को स्पष्ट करने में सहायता करती हैं (नेरुर एट अल., 2016; रोंडा-पुपो और गुएरास-मार्टिन, 2012; टैन एवं डिंग, 2015)। ग्रंथमितीय विश्लेषण का एक महत्त्वपूर्ण भाग सह-लेखकत्व (Co-authorship) विश्लेषण उन नेटवर्कों की जांच करता है, जो शोधकर्ता द्वारा वैश्विक स्तर पर अन्य लेखकों के साथ मिलकर संयुक्त प्रकाशनों के माध्यम से निर्मित किया गया है (एसीडो एट अल., 2006)। सह-लेखकत्व विश्लेषण से यह स्पष्ट होता है कि लेखक ने अपनी अनुसंधान रुचि के क्षेत्रों में किन-किन लेखकों के साथ अकादमिक सम्बन्ध निर्मित किया है। इसके द्वारा लेखक की दलगत भावना और आपसी सहयोग का भी वैज्ञानिक अनुमान लगाया जा सकता है।

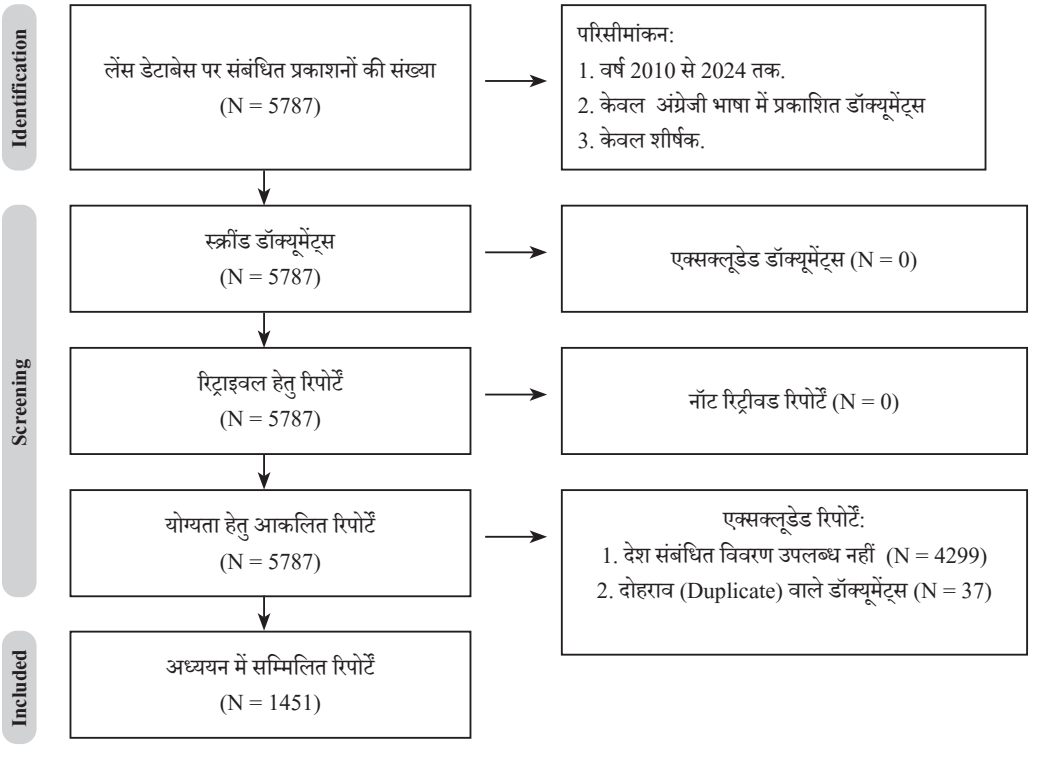
शोध उद्देश्य

इस शोध अध्ययन का उद्देश्य शैक्षिक आकलन के विभिन्न आयामों के संदर्भ में किए जा चुके प्रकाशनों का मात्रात्मक विश्लेषण और वैज्ञानिक दृश्यीकरण करते हुए शैक्षिक आकलन संबंधित अध्ययनों के अकादमिक विकास और अनुसंधान प्रवृत्तियों का विवरण प्रस्तुत करना एवं शैक्षिक आकलन के क्षेत्र में शीर्ष उत्पादक देशों, लेखकों, स्रोतों और लोकप्रिय मुख्य शब्दों (ट्रेंडिंग कीवर्ड्स) का पता लगाना है।

शोध योजना एवं प्रविधि

इस शोध अध्ययन को पूर्ण करने के लिए इसकी मात्रात्मक प्रकृति को ध्यान में रखते हुए मात्रात्मक शोध उपागम का प्रयोग किया गया। इस अध्ययन को ग्रंथमितीय विश्लेषण विधि द्वारा पूर्ण किया गया है। इस अध्ययन में वर्ष 2010 से लेकर 2024 (16/09/2024, अपराह्न 23:30) तक शैक्षिक आकलन संबंधित प्रकाशित प्रकाशनों का ही उपयोग किया गया है। प्रदत्त संकलन के लिए लेंस डेटाबेस (https://www.lens.org) पर ''शैक्षिक आकलन'' सर्च करके वर्ष 2010-2024 तक उपलब्ध प्रकाशनों को सीएसवी फ़ाइल के रूप में संकलित किया गया। संकलित फ़ाइल की एम.एस. एक्सेल (2021) सॉफ्टवेयर की सहायता से प्रदत्तों की सफाई (डेटा क्लीनिंग) की गई। इसके लिए एक्सेल में विभिन्न फिल्टर लगाकर अधूरी सूचनाओं (प्रकाशन वर्ष, देश, अनुसंधानकर्त्ता इत्यादि से संबंधित स्पष्ट सूचना का अभाव) वाले प्रकाशनों को हटा दिया गया। इस प्रकार अंतिम रूप से कुल 1451 प्रकाशनों को सीएसवी फ़ाइल के रूप में संकलित किया गया। संकलित कुल 1451 प्रकाशनों का वोसव्युवर (1.6.20 संस्करण) सॉफ्टवेयर की सहायता से विश्लेषण किया गया। वैज्ञानिक मानचित्रण के क्षेत्र में वोसव्युवर एक बेहतरीन सॉफ्टवेयर है। वोसव्युवर सॉफ्टवेयर का अद्यतन संस्करण (Version 1.6.20) एमएस विंडोज, मैक ओएस और अन्य ऑपरेटिंग सिस्टम्स के लिए 31 अक्तूबर, 2023 से किसी भी उद्देश्य से प्रयोग करने के लिए मुफ्त में उपलब्ध है, जिसे वेबसाइट (https://www.vosviewer.com/download) से डाउनलोड किया जा सकता है। शोधार्थी ने इस अध्ययन हेतु संकलित प्रकाशनों को प्राप्त करने के लिए प्रिज्मा (PRISMA) गाइडलाइन (पेज एट अल., 2021) का प्रयोग किया गया है, जिसका विवरण चित्र-1 में प्रस्तुत किया गया है:-

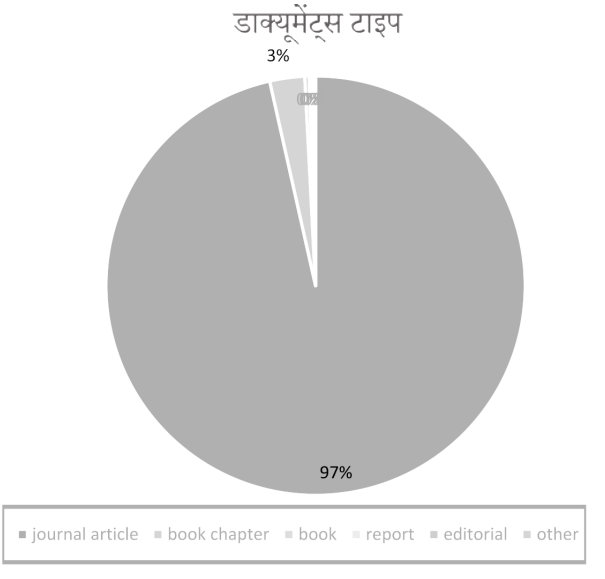
चित्र-1: शैक्षिक आकलन संबंधित प्रकाशनों की पहचान एवं डेटासेट संकलित करना



स्रोत: पेज एट आल (2021) द्वारा प्रस्तुत प्रारूप को लेखक द्वारा संशोधित करके उपयोग किया गया है।

प्रिज्मा (2021) दिशानिर्देश का प्रयोग करते हुए लेखक द्वारा अंतिम रूप से कुल 1451 डॉक्यूमेंट्स की सीएसवी फ़ाइल लेंस डेटाबेस से डाउनलोड की गई। उक्त डाउनलोड फ़ाइल का एक्सेल सॉफ्टवेयर की सहायता से डॉक्यूमेंट्स टाइप-वार विश्लेषण किया गया। समस्त फ़ाइल का डॉक्यूमेंट्स टाइप-वार विवरण चित्र-2 में पाई चार्ट के रूप में प्रस्तुत किया गया है:

चित्र-2: डाउनलोड किए गए समस्त डॉक्यूमेंट्स का डॉक्यूमेट टाइप-वार विवरण



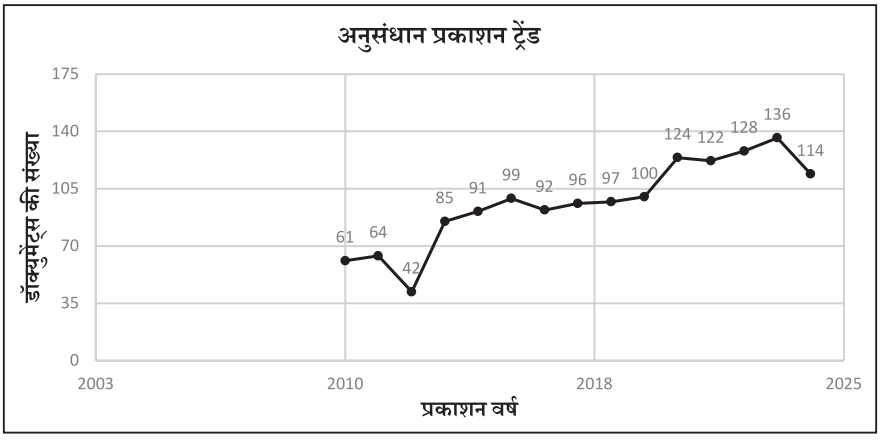
स्रोत: एम.एस. एक्सेल- 2021 सॉफ्टवेयर की सहायता से लेखक द्वारा निर्मित

शोध परिणाम

शैक्षिक आकलन संबंधित वैश्विक अनुसंधान प्रकाशन ट्रेंड एवं देश

वैश्विक स्तर पर शैक्षिक आकलन हमेशा से लेखकों के लिए महत्त्वपूर्ण विषय रहा है, क्योंकि अलग-अलग भौगोलिक परिस्थिति में अधिगमकर्त्ताओं की अधिगम प्रक्रिया अलग-अलग होती है। अधिगमकर्त्ताओं की शारीरिक और मानसिक स्थिति भी बहुत हद तक उनके भौगोलिक अवस्थिति से प्रभावित होती है, क्योंकि किसी भी स्थान की भौगोलिक स्थिति के सापेक्षतया ही सामाजिक-सांस्कृतिक वातावरण का निर्माण होता है। इसके साथ ही बदलती प्रौद्योगिकी भी अधिगम प्रक्रिया को अपने साथ-साथ बदलती रहती है। इसीलिए बदलती भौगोलिक, सामाजिक और प्रौद्योगिक वातावरण में शैक्षिक आकलनकर्त्ताओं के समक्ष नवीन समस्याएँ उत्पन्न होती रही हैं। इन समस्याओं पर अनुसंधान करके वैश्विक लेखकों ने महत्त्वपूर्ण शोध कार्य प्रकाशित किया है। वर्ष 2010-2024 तक शैक्षिक आकलन के विभिन्न आयामों से संबंधित कुल 1451 प्रकाशन अभी तक किए गए हैं। चित्र-2 में वर्ष 2010 से 2024 तक प्रकाशित कुल प्रकाशन ट्रेंड को वार्षिक आधार पर प्रस्तुत किया गया है:

चित्र-2: शैक्षिक आकलन संबंधित प्रकाशन ट्रेंड (वर्ष 2010 से 2024 तक)

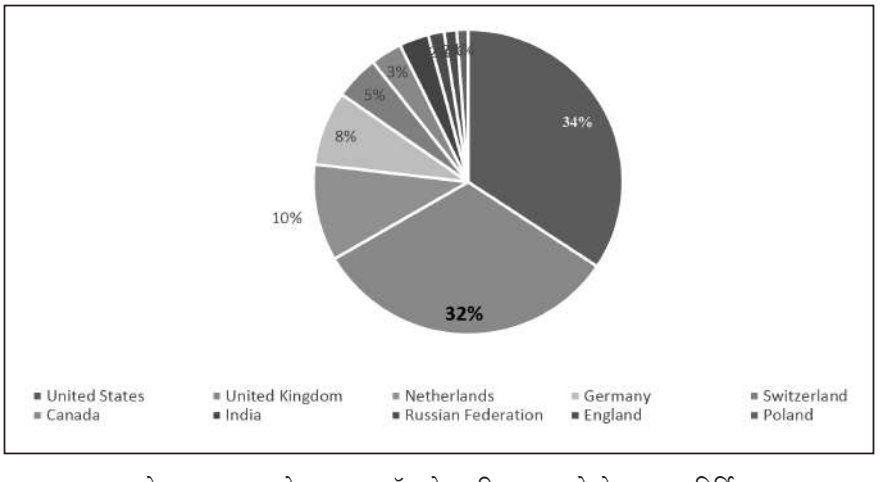


स्रोत: एम.एस. एक्सेल- 2021 सॉफ्टवेयर की सहायता से लेखक द्वारा निर्मित

उपर्युक्त चित्र-2 के अवलोकन से स्पष्ट है कि वर्ष 2010-2024 के दौरान वैश्विक स्तर पर शैक्षिक आकलन संबंधी कुल 1451 प्रकाशन हुए हैं। सर्वाधिक प्रकाशन (136) वर्ष 2023 में हुए हैं, जबकि सबसे कम प्रकाशन (42) वर्ष 2012 में हुए हैं। इसी प्रकार अन्य वर्षों में प्रकाशित प्रकाशनों की कुल संख्या को चित्र-2 में देखा जा सकता है।

वोसव्युवर सॉफ्टवेयर की सहायता से कुल संकलित 1451 प्रकाशनों का विश्लेषण करने से पता चलता है कि ये प्रकाशन कुल 61 देशों के लेखकों द्वारा किए गए हैं। उक्त देशों द्वारा प्रकाशित कुल प्रकाशनों का एक्सेल सॉफ्टवेयर की सहायता से विश्लेषण करने पर ज्ञात हुआ कि कुल 61 देशों में से सर्वाधिक (N = 435, लगभग 34%) प्रकाशन अकेले संयुक्त राज्य अमेरिका ने किया है। शैक्षिक आकलन संबंधित सर्वाधिक प्रकाशन करने वाले शीर्ष 10 देशों का विवरण चित्र-3 में प्रस्तुत है:

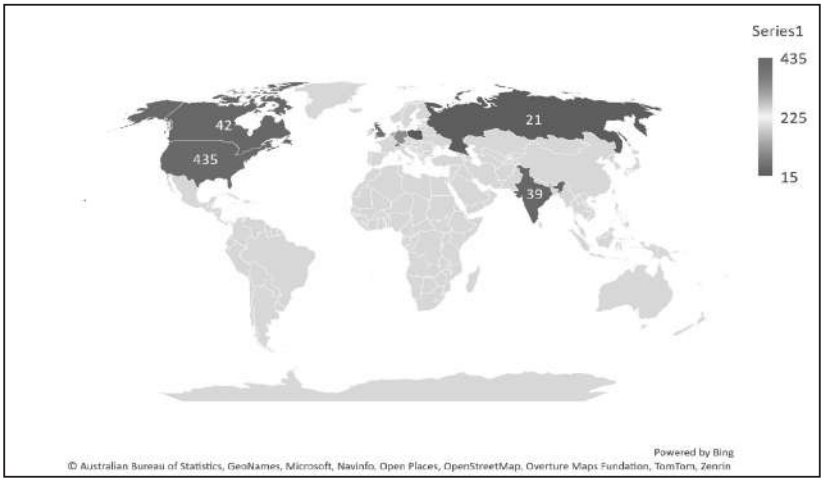
चित्र-3: शैक्षिक आकलन संबंधी अनुसंधान उत्पादक शीर्ष 10 देश



स्रोत: एम.एस. एक्सेल- 2021 सॉफ्टवेयर की सहायता से लेखक द्वारा निर्मित

उपर्यक्त चित्र-3 के अवलोकन से स्पष्ट है कि शैक्षिक आकलन संबंधित अनुसंधान प्रकाशन करने वाले 61 देशों में से सर्वाधिक उत्पादन करने वाले शीर्ष 10 देशों की सूची में कुल 435 (34%) प्रकाशन के साथ संयुक्त राज्य अमेरिका प्रथम स्थान पर है। अमेरिका के बाद यूके 409 (32%) प्रकाशनों के साथ द्वितीय स्थान पर है। इसी प्रकार शीर्ष 10 उत्पादक देशों की सूची में अन्य 8 देश क्रमशः नीदरलैंड (10%), जर्मनी (8%), स्विट्ज़रलैंड (5%), कनाडा (3%) भारत (3%), रूस (2%), इंग्लैंड (2%) और पोलैंड (1%) हैं। शीर्ष 10 उत्पादक देशों की सूची में दक्षिण एशिया का एकमात्र देश, भारत है। शैक्षिक आकलन के संदर्भ में वर्ष 2010 से 2024 के मध्य भारत ने 39 (कुल प्रकाशनों का लगभग 3%) प्रकाशन उत्पादित किया है। उक्त शीर्ष 10 देशों को उनकी प्रकाशन सघनता के आधार पर उनका मानचित्र चित्र-4 में देखा जा सकता है।

चित्र-4: शीर्ष 10 उत्पादक देशों का मानचित्र



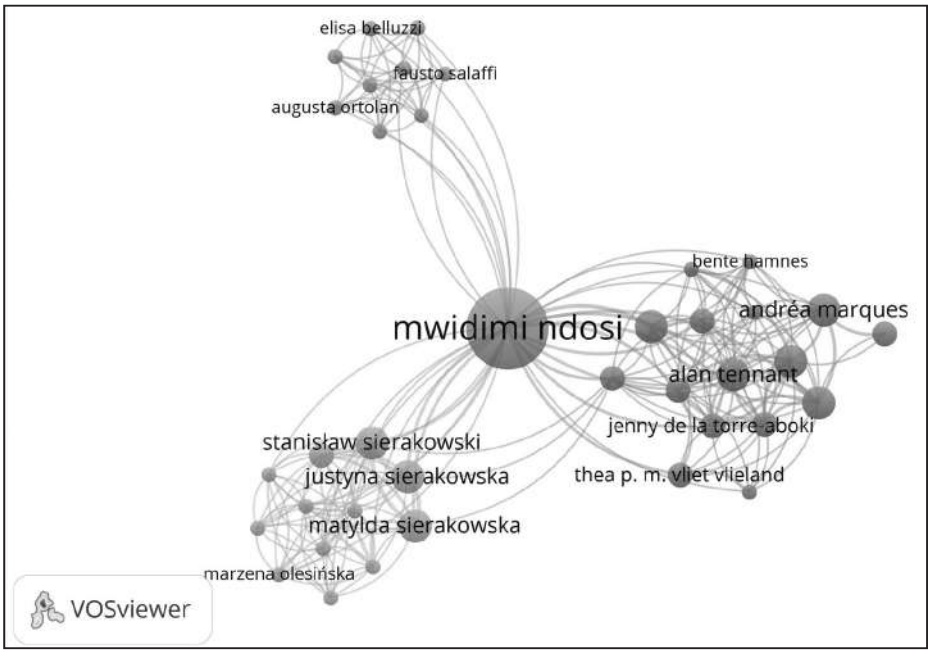
स्रोत: एम.एस. एक्सेल- 2021 सॉफ्टवेयर की सहायता से लेखक द्वारा निर्मित

शैक्षिक आकलन संबंधित प्रकाशन और को-ऑथरशिप विश्लेषण

वोसव्युवर मुफ़्त में उपलब्ध एक कंप्यूटर सॉफ्टवेयर है, जिसकी सहायता से ग्रंथमितीय मानचित्र का निर्माण एवं दृश्यांकन किया जाता है (वान एक एवं वाल्टमन, 2010)। वास्तव में वोस (VOS) 'समानता का दृश्यांकन' (Visu_alization Of Similarities) का संक्षिप्त रूप है, जो ऑब्जेक्ट्स के मध्य समानता को प्रदर्शित करता है (वान एक एवं वाल्टमन, 2007)। यह सॉफ्टवेयर अपने को-ऑथरशिप विकल्प की सहायता से विश्लेषित की जा रही ग्रंथ-सूची से संबंधित प्रकाशन करने वाले लेखकों के नेटवर्क, दृश्यीकरण मानचित्र, ओवरले दृश्यीकरण मानचित्र और सघनता दृश्यीकरण मानचित्र को उत्पादित करता है ((वान एक एवं वाल्टमन, 2011)। नेटवर्क दृश्यीकरण मानचित्र में गोले का आकार संबंधित अनुसंधानकर्त्ता के प्रकाशनों की संख्या को प्रस्तुत करता है; अर्थात जो गोला जितना अधिक बड़ा होगा, उस अनुसंधानकर्त्ता के पास उतने ही अधिक प्रकाशन होंगे। इससे लेखकों के आपसी जुड़ाव (लिंक्स) और कुल लिंक स्ट्रेंथ सहित विवरण की समझ आसानी से आ जाती है। इसी प्रकार सघनता दृश्यीकरण मानचित्र में जिस अनुसंधानकर्त्ता का रंग जितना अधिक गहरा दिखाई देता है, उस अनुसंधानकर्त्ता के पास अन्य लेखकों की तुलना में अधिक प्रकाशन होते हैं।। शैक्षिक आकलन संबंधित कुल 1451 प्रकाशनों की सीएसवी फ़ाइल को

वोसव्युवर सॉफ्टवेयर के 'को-ऑथरशिप' विकल्प को चलाने पर कुल 5372 लेखकों का विवरण प्राप्त हुआ। 5372 लेखकों में से सर्वाधिक लिंक्स का सृजन करने वाले 1000 लेखकों का विश्लेषण वोसव्युवर सॉफ्टवेयर की सहायता से करने पर प्राप्त हुआ कि केवल 38 लेखक ही आपस में जुड़े हुए हैं। 38 जुड़े हुए लेखक 3 क्लस्टर्स और 236 लिंक्स का निर्माण करते हैं। उक्त 38 लेखकों का कुल लिंक स्ट्रेंथ 278 है। इससे स्पष्ट है कि इन लेखकों का आपस में बहुत मजबूत अकादमिक नेटवर्क है। उक्त लेखकों का वैज्ञानिक नेटवर्क दृश्यीकरण मैपिंग चित्र-5 की सहायता से देखा जा सकता है।

चित्र-5: कुल लेखकों का नेटवर्क दृश्यीकरण मानचित्र



विवरण: 38 परस्पर जुड़े हुए (कनेक्टेड) लेखकों का सघनता दृश्यीकरण मानचित्र

शीर्ष 15 उत्पादक अनुसंधानकर्त्ता

शीर्ष उत्पादक लेखकों का विश्लेषण करने के लिए को-ऑथरशिप विकल्प में कम से कम 4 प्रकाशन और कम से कम 1 उद्धरण (साइटेशन) मानदंड को निर्धारित करने पर कुल 15 शीर्ष अनुसंधानकर्त्ता प्राप्त हुए। उक्त शीर्ष 15 उत्पादक लेखकों का विवरण तालिका-1 में प्रस्तुत किया गया है:

तालिका-1: शीर्ष 10 उत्पादक लेखकों का विवरण

क्र. सं.	अनुसंधानकर्त्ता	कुल प्रकाशन	कुल उद्धरण (साइटेशंस)	उद्धरण (साइटेशंस)/ प्रकाशन
1	मिदमी, न्दोसी	11	175	15.90
2	पैट्रिस, लाज़ुर	6	78	13.00
3	डेविड ए. कुक	5	681	136.20
4	थेरेसी एन. होपफेनबेक	5	72	14.40
5	अली, मेहदी	5	1	0.20
6	जॉर्जेस, नखौल	5	1	0.20
7	एस. बेथ बियरर	5	1	0.20
8	सुसाना, एरिगैन	5	1	0.20
9	रोज, हटाला	4	571	142.75
10	जेसी डी. शोल्ड	4	1	0.25

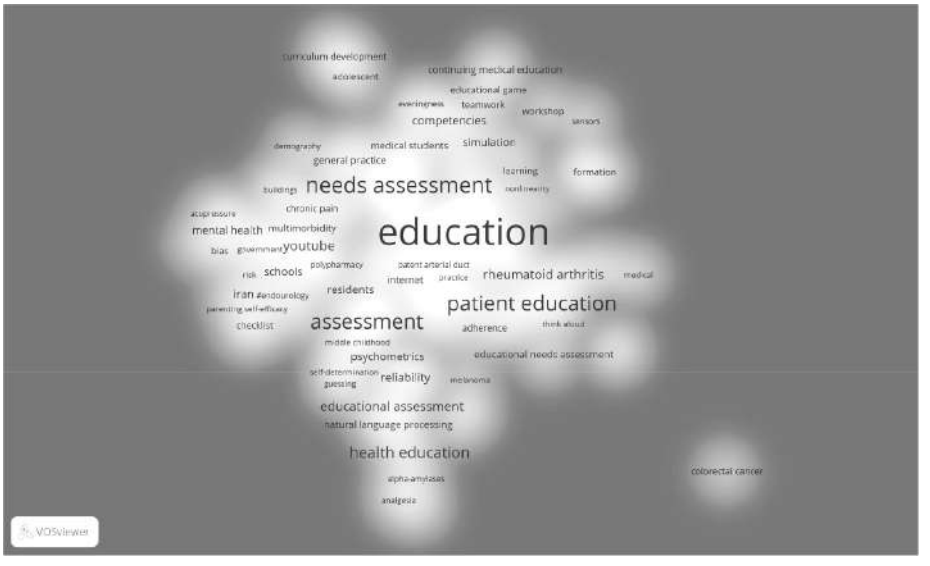
स्रोत: लेखक द्वारा निर्मित

उपर्युक्त तालिका-1 के अवलोकन से स्पष्ट है कि सर्वाधिक उत्पादक लेखक मिदमी, न्दोसी हैं। न्दोसी ने शैक्षिक आकलन के संदर्भ में कुल 11 प्रकाशन किए हैं; जिस पर उन्हें कुल 175 उद्धरण प्राप्त हुए हैं; और उनका प्रति प्रकाशन उद्धरण दर 15.90 है। सर्वाधिक उत्पादक लेखकों में दूसरे स्थान पर पैट्रिस, लाज़ुर हैं। पैट्रिस के प्रकाशनों की कुल संख्या 6 है, जिन पर उन्हें कुल 78 उद्धरण प्राप्त हुए हैं। पैट्रिस का प्रति प्रकाशन उद्धरण दर 13.00 है। इसी तरह शीर्ष 10 उत्पादक लेखकों में से अन्य 8 लेखकों के प्रकाशन और उद्धरणों की संख्या एवं प्रति प्रकाशन उद्धरण की दर संबंधी विवरण उपर्युक्त तालिका-1 में देखा जा सकता है। को-ऑथरशिप विश्लेषण से स्पष्ट है कि शैक्षिक आकलन संबंधी शीर्ष 10 अनुसंधान उत्पादक लेखकों में भारत का एक भी लेखक नहीं है।

शैक्षिक आकलन संबंधित प्रकाशन में मुख्य शब्दों की आवृत्ति (कीवर्ड्स ऑकरेंस)

वैश्विक स्तर पर शैक्षिक आकलन के विभिन्न आयामों के संदर्भ में किए जा चुके प्रकाशनों में प्रयुक्त किए गए मुख्य शब्द (कीवर्ड्स) का अधिक सारगर्भित विश्लेषण करने के लिए वोसव्युवर सॉफ्टवेयर की सहायता से को-आकरेंस विद अदर कीवर्ड्स ऑप्शन को चलाया गया। उत्पाद के रूप में 1451 प्रकाशनों में प्रयुक्त कुल 1395 मुख्य शब्द प्राप्त हुए; उनमें से 804 मुख्य शब्द आपस में जुड़कर (लिंक्ड होकर) कुल 45 क्लस्टर्स और 3052 लिंक्स का निर्माण करते हैं। उक्त 804 मुख्य शब्दों का कुल लिंक स्ट्रेंथ 3127 है। इससे स्पष्ट है कि शैक्षिक आकलन वैश्विक स्तर पर ज्ञान के विविध अनुशासनों एवं आयामों के लिए कितना अधिक महत्त्वपूर्ण और उपयोगी है। मुख्य शब्दों के विश्लेषण का दृश्यीकरण करने हेतु वोसव्युवर सॉफ्टवेयर की सघनता दृश्यीकरण मानचित्र फीचर का प्रयोग किया गया है। उक्त लिंक्ड मुख्य शब्दों की सघनता दृश्यीकरण मानचित्र को चित्र-6 में प्रस्तुत किया गया है:

चित्र-6: मुख्य शब्दों की आवृत्ति (कीवर्ड्स ऑकरेंस) का नेटवर्क दृश्यीकरण मानचित्र



विवरण: कीवर्ड्स ऑकरेंस का सघनता दृश्यीकरण मानचित्र

शीर्ष 10 मुख्य शब्द (कीवर्ड्स)

चित्र-6 में प्रस्तुत कीवर्ड्स सघनता मानचित्र का अवलोकन करने से यह तो स्पष्ट है कि शैक्षिक आकलन का वैश्विक स्तर के विभिन्न ज्ञानानुशासनों से बहुत गहरा संबंध है। कुल 1451 प्रकाशनों में कुल 1395 मुख्य शब्द प्रयुक्त हुए हैं। वैश्विक स्तर पर ट्रेंड करने वाले महत्त्वपूर्ण मुख्य शब्दों पता लगाने के लिए उनकी आवृत्ति के बढ़ते क्रम में वोसव्युवर सॉफ्टवेयर की सहायता से चेक किया गया। कम से कम 7 आवृत्ति वाले मानदंड पर शीर्ष 10 मुख्य शब्द प्राप्त हुए। उक्त शीर्ष 10 मुख्य शब्द आपस में जुड़कर कुल 4 क्लस्टर्स और 15 लिंक्स का निर्माण करते हैं और उनका कुल लिंक स्ट्रेंथ 26 है। सर्वाधिक आवृत्ति वाले उक्त शीर्ष 10 मुख्य शब्द को उनकी आवृत्ति संख्या और कुल लिंक स्ट्रेंथ के साथ तालिका-2 में प्रस्तुत किया गया है-

तालिका-2: शीर्ष 15 मुख्य शब्द (कीवर्ड्स) का विवरण

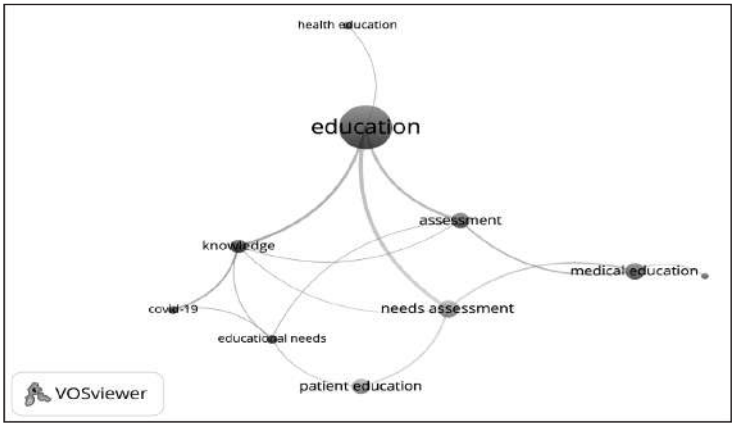
क्रम सं.	मुख्य शब्द (कीवर्ड्स)	आवृत्ति (ऑकरेंस)	कुल लिंक स्ट्रेंथ (कुल लिंक सामर्थ्य)
1	एजुकेशन	51	11
2	नीड्स एसेसमेंट	20	9
3	मेडिकल एजुकेशन	19	5
4	एसेसमेंट	18	7

5	पेटेंट एजुकेशन	18	3
6	नॉलेज	16	8
7	एजुकेशनल नीड्स	10	4
8	कोविड-19	9	3
9	हेल्थ एजुकेशन	9	1
10	यूट्यूब	7	1

स्रोत: लेखक द्वारा निर्मित

उपर्युक्त तालिका-2 से स्पष्ट है कि शैक्षिक आकलन संबंधी वैश्विक अनुसंधान प्रकाशनों में प्रयुक्त जिन शीर्ष 10 मुख्य शब्दों की आवृत्ति सर्वाधिक बार हुई है, उनमें सर्वाधिक (N = 51) आवृत्ति वाला मुख्य शब्द एजुकेशन है। इसका कुल लिंक स्ट्रेन्थ 11 है। इसी तरह अन्य मुख्य शब्द- नीड्स एसेसमेंट (20), मेडिकल एजुकेशन (19), असेसमेंट (18), पेटेंट एजुकेशन (18), नॉलेज (16), एजुकेशनल नीड्स (10), कोविड-19 (9), हेल्थ एजुकेशन (9) और यूट्यूब (7) हैं। उक्त शीर्ष 10 मुख्य शब्द आपस में जुड़कर 4 क्लस्टर्स का निर्माण करते हैं। प्रथम क्लस्टर को लाल, द्वितीय क्लस्टर को हरा, तृतीय क्लस्टर को नीला और चतुर्थ क्लस्टर को पीले रंग से दिखाया गया है। प्रथम क्लस्टर में 3 मुख्य शब्द (नॉलेज, एजुकेशनल नीड्स और कोविड-19), द्वितीय क्लस्टर में भी 3 मुख्य शब्द (मेडिकल एजुकेशन, एसेसमेंट और यूट्यूब), तृतीय क्लस्टर में 2 मुख्य शब्द (एजुकेशन और हेल्थ एजुकेशन) और चतुर्थ क्लस्टर में 2 मुख्य शब्द (नीड्स एसेसमेंट और पेटेंट एजुकेशन) हैं। उक्त 4 क्लस्टर्स में सम्मिलित शीर्ष 10 मुख्य शब्दों का नेटवर्क दृश्यीकरण मानचित्र को चित्र-7 की सहायता से देखा जा सकता है।

चित्र-7: शीर्ष 15 मुख्य शब्द (कीवर्ड्स) का नेटवर्क दृश्यीकरण मानचित्र



स्रोत: वोसव्युवर सॉफ्टवेयर द्वारा शीर्ष मुख्य शब्दों (कीवर्ड्स) के नेटवर्क दृश्यीकरण मानचित्र आउटपुट का स्क्रीनशॉट

शैक्षिक आकलन एवं सर्वाधिक उत्पादक स्रोत

शैक्षिक आकलन संबंधी कुल 1451 प्रकाशन वैश्विक स्तर पर कुल 919 स्रोतों (पत्रिकाओं) द्वारा प्रकाशित किए गए हैं। उक्त 919 पत्रिकाएँ, 831 क्लस्टर्स और 133 लिंक्स का निर्माण करती हैं, जिनका कुल लिंक स्ट्रेंथ 140 है। इससे स्पष्ट है कि ये स्रोत आपस में बहुत कम जुड़े हुए हैं। इनके सघनता दृश्यीकरण मानचित्र को चित्र-8 में प्रस्तुत किया गया है:

चित्र-8: सभी प्रकाशन स्रोतों का सघनता दृश्यीकरण मानचित्र

स्रोत: स्वनिर्मित

शीर्ष 10 स्रोत

कुल 919 स्रोतों में से सर्वाधिक संख्या में प्रकाशन करने वाले स्रोतों का विश्लेषण करने हेतु वोसव्युवर सॉफ्टवेयर के 'टाइप ऑफ एनालिसिस- साइटेशन विथ यूनिट ऑफ एनालिसिस- सोर्सेस' विकल्प को चलाया गया। कम से कम 9 डॉक्यूमेंट्स और कम से कम 24 साइटेशन उपयुक्त मानदंड पर पाए जाने पर शीर्ष 10 स्रोत प्राप्त हुए, जिनका विवरण तालिका-3 में प्रस्तुत किया गया है:

तालिका-3: शीर्ष 10 अनुसंधान उत्पादक स्रोत

क्रम सं.	पत्रिका	डॉक्यूमेंट्स	उद्धरण (साइटेशंस)	उद्धरण (साइटेशंस)/ डॉक्यूमेंट्स
1	एसेसमेंट इन एजुकेशन: प्रिंसिपल्स, पॉलिसी एंड प्रैक्टिस	22	317	14.41

2	एजूकेशनल मेजरमेंट: इशूज एंड प्रैक्टिस	19	403	21.21
3	लेक्चर नोट्स इन कंप्यूटर साइंस	18	86	4.78
4	बीएमसी मेडिकल एजुकेशन	14	219	15.64
5	एकेडमिक मेडिसिन: जर्नल ऑफ द एसोसिएशन ऑफ अमेरिकन मेडिकल कालेजेस	11	674	61.27
6	एजुकेशनल साइकोलोजी इन प्रैक्टिस	11	74	6.72
7	जर्नल ऑफ एजुकेशन एंड हेल्थ प्रोमोशन	11	48	4.36
8	सस्टेनेबिलिटी	11	215	19.54
9	एजुकेशन एंड इन्फोर्मेशन टेक्नॉलॉजी	9	66	7.33
10	हाइजीन एंड सेनिटेशन	9	24	2.67

स्रोत: लेखक द्वारा निर्मित

उपर्युक्त तालिका-3 के अवलोकन से स्पष्ट है कि वैश्विक स्तर पर शैक्षिक आकलन संबंधी सर्वाधिक प्रकाशन करने वाले शीर्ष 10 स्रोत- एसेसमेंट इन एजुकेशन: प्रिंसिपल्स, पॉलिसी एंड प्रैक्टिस (22 प्रकाशन, 317 साइटेशन), एजुकेशनल मेजरमेंट: इशू एंड प्रैक्टिस (19 प्र. 403 सा.), लेक्चर नोट्स इन कंप्यूटर साइंस (18 प्र. 86 सा.), बीएमसी मेडिकल एजुकेशन (14 प्र. 219 सा.), एकेडमिक मेडिसिन: जर्नल ऑफ द एसोसिएशन ऑफ अमेरिकन मेडिकल कालेजेस (11 प्र. 676 सा.), एजुकेशनल साइकोलोजी इन प्रैक्टिस (11 प्र. 74 सा.), जर्नल ऑफ एजुकेशन एंड हेल्थ प्रोमोशन (11 प्र. 48 सा.), सस्टेनेबिलिटी (11 प्र. 215 सा.), एजुकेशन एंड इन्फोर्मेशन टेक्नॉलॉजी (9 प्र. 66 सा.) और हाइजीन एंड सेनिटेशन (9 प्र. 24 सा.) हैं। उक्त सभी शीर्ष 10 स्रोतों का प्रति डॉक्यूमेंट साइटेशन दर क्रमशः 14.41, 21.21, 4.78, 15.64, 61.27, 6.72, 4.36, 19.54, 7.33 और 2.67 है।

शीर्ष 10 डॉक्यूमेंट्स

कुल 1451 प्रकाशनों में से सर्वाधिक संख्या में उद्धरण प्राप्त करने वाले शीर्ष 10 प्रकाशनों का विश्लेषण करने हेतु वोसव्युवर सॉफ्टवेयर के 'टाइप ऑफ एनालिसिस- साइटेशन विद यूनिट ऑफ एनालिसिस- डॉक्यूमेंट्स' विकल्प को चलाया गया। डॉक्यूमेंट्स को प्राप्त उद्धरणों की संख्या के बढ़ते क्रम में जांचा गया। अंततः कम से कम 135 साइटेशंस के मापदंड पर शीर्ष 10 डॉक्यूमेंट्स प्राप्त हुए, जिनका विवरण तालिका- 4 में प्रस्तुत किया गया है:

तालिका-4: शीर्ष 10 शोध पत्र

क्रम सं.	लेखक	शीर्षक	उद्धरण (साइटेशंस)	पत्रिका व प्रकाशक
1	(ब्रूखार्ट, 2011)	एजुकेशनल असेसमेंट: नॉलेज एंड स्किल्स फॉर टीचर्स	275	स्पेशल मेजरमेंट: इशूज एंड प्रैक्टिसेस (विले पब्लिकेशन्स)
2	(रेली एट अल., 2019)	जेंडर डिफरेंसेस इन रीडिंग एंड राइटिंग अचीवमेंट: एविडेंस फ्रॉम द नेशनल असेसमेंट ऑफ एजुकेशनल प्रोग्रेस (एनएईपी)	272	द अमेरिकन साइकोलॉजिस्ट (अमेरिकन साइकोलॉजिकल एसोसिएशन)
3	(कुक व हटला, 2016)	वैलिडेशन ऑफ एजुकेशनल असेसमेंट्स: ए प्रीमायर फॉर सिमुलेशन एंड बियॉन्ड	242	एडवांसेज इन सिमुलेशन (बीएमसी, स्प्रिंगर नेचर इंग्लैंड)
4	(कामेन्स व मैकनीली, 2010)	ग्लोबलाइज़ेशन एंड द ग्रोथ ऑफ इंटरनेशनल एजुकेशनल टेस्टिंग एंड नेशनल असेसमेंट	222	कम्परेटिव एजुकेशन रिव्यु (यूनिवर्सिटी ऑफ शिकागो प्रेस)
5	(ब्राइजेस एट अल., 2015)	लिंकिंग सिमुलेशन बेस्ट एजुकेशनल असेसमेंट्स एंड पेटेंट रिलेटेड आउटकम्स: ए सिस्टेमैटिक रिव्यु एंड मेटा-एनालिसिस	207	ऐकेडमिक मेडिसिन: जर्नल ऑफ द एसोसिएशन ऑफ अमेरिकन मेडिकल कॉलेजेज (लिपिनकॉट विलियम्स एंड विलकिंस)
6	(मैकुलॉ एट अल., 2011)	असेसमेंट ऑफ द फार्माकोजेनोमिक्स एजुकेशनल नीड्स ऑफ फार्मासिस्ट	168	अमेरिकन जर्नल ऑफ फार्मास्यूटिकल एजुकेशन (एलजेवियर बीवी)
7	(गोबर्ट एट अल., 2013)	फ्रॉम लॉग फाइल्स टू असेसमेंट मैट्रिक्स: मीजरिंग स्टूडेंट्स साइंस इन्क्वायरी स्किल्स यूजिंग एजुकेशनल डेटा माइनिंग	164	जर्नल ऑफ द लर्निंग साइंसेज (इनफार्मा यूके लिमिटेड)
8	(रेली एट अल., 2014)	सेक्स डिफरेंसेस इन मैथमेटिक्स एंड साइंस अचीवमेंट: ए मेटा-एनालिसिस ऑफ नेशनल असेसमेंट ऑफ एजुकेशनल प्रोग्रेस असेसमेंट	144	जर्नल ऑफ एजुकेशनल साइकोलॉजी (अमेरिकन साइकोलॉजिकल एसोसिएशन)

9	(वोगेल-वालकट एट अल., 2012)	द डिफिनिशन, असेसमेंट, एंड मिटिगेशन ऑफ स्टेट बोरेडम विदिन एजुकेशनल सेटिंग्स: ए कॉम्प्रिहेंसिव रिव्यु	136	एजुकेशनल साइकोलॉजी रिव्यु (स्प्रिंगर साइंस एंड बिज़नेस मीडिया, एलएलसी)
10	(ग्रीफ एट अल., 2013)	कॉम्प्लेक्स प्रॉब्लम सॉल्विंग इन एजुकेशनल कॉन्टेक्ट्स- समथिंग बियॉन्ड जी: कॉन्सेप्ट, एसेसमेंट, मेजरमेंट इन्वैरियन्स एंड कंस्ट्रक्ट वैलिडिटी	135	जर्नल ऑफ एजुकेशनल साइकोलॉजी (अमेरिकन साइकोलॉजिकल एसोसिएशन)

स्रोत: लेखक द्वारा निर्मित

निष्कर्ष

इस शोधपत्र में शैक्षिक आकलन संबंधी वैश्विक अनुसंधान ट्रेंड का ग्रंथमितीय विश्लेषण प्रस्तुत किया गया है। इस अध्ययन में वर्ष 2010 से लेकर 16 सितंबर, 2024 तक शैक्षिक आकलन के संदर्भ में संपूर्ण विश्व में प्रकाशित किए जा चुके शोध अध्ययनों का ग्रंथमितीय विश्लेषण करने के लिए 'लेंस डेटाबेस' से सीएसवी फाइल एक्सट्रैक्ट किया गया और एक्सेल सॉफ्टवेयर की सहायता से डेटा साफ़ (डेटा क्लीनिंग) करते हुए शैक्षिक आकलन संबंधी अनुसंधान कार्यों का वार्षिक विवरण और देश के आधार पर प्रकाशनों की संख्या तथा सर्वाधिक उत्पादक देशों के मानचित्र को तैयार किया गया। इसके अतिरिक्त सर्वाधिक उत्पादन करने वाले लेखकों, पत्रिकाओं इत्यादि का विश्लेषण वोसव्युअर सॉफ्टवेयर की सहायता से किया गया। साथ ही वोसव्युवर सॉफ्टवेयर की सहायता से ही मुख्य शब्दों की आवृत्ति का विश्लेषण करते हुए विभिन्न प्रकार के अकादमिक लिंक्स का वैज्ञानिक मानचित्रण भी किया गया। शैक्षिक आकलन संबंधित सबसे अधिक प्रकाशन वर्ष 2023 में तथा सबसे कम प्रकाशन वर्ष 2012 में प्रकाशित हुए हैं। शैक्षिक आकलन संबंधी अनुसंधान उत्पादक देशों में संयुक्त राज्य अमेरिका और यूके क्रमशः प्रथम और द्वितीय शीर्ष अनुसंधान उत्पादक देश हैं। भारत शीर्ष उत्पादक देशों की सूची में सातवें स्थान पर है। कुल 5272 लेखकों ने 1395 अन्य मुख्य शब्दों का प्रयोग करते हुए कुल 1451 डॉक्यूमेंट्स, 919 स्रोतों की सहायता से प्रकाशित किए हैं। इस अध्ययन की सबसे बड़ी सीमा यह है कि इसमें केवल अंग्रेजी भाषा में प्रकाशित और केवल लेंस डेटाबेस पर उपलब्ध डॉक्यूमेंट्स का विश्लेषण किया गया है। यह शोध कार्य शैक्षिक आकलन के क्षेत्र में अनुसंधान करने वाले शोधार्थियों के लिए बहुत महत्त्वपूर्ण है। इस शोधपत्र की सहायता से नवीन शोधार्थी एवं अध्यापक, शैक्षिक आकलन से संबंधित सबसे अधिक उत्पादन करने वाले देशों, लेखकों, स्रोतों, शोधपत्रों और लोकप्रिय मुख्य शब्दों को आसानी से एक्सेस कर सकते हैं।

संदर्भ सूची

एईआरए (1999). स्टैंडर्ड्स. (एन.डी.). https://www.aera.net/Publications/Books/Standards-1999-Ed

एसिडो, एफ., बार्रोसो, सी., रोचा, सी., एवं गालान, जे. (2006). को-आथरशिप इन मैनेजमेंट एंड ऑर्गनाइज़ेशनल स्टडीज़: एन एम्पिरिकल एंड नेटवर्क एनालिसिस. जर्नल ऑफ मैनेजमेंट स्टडीज़, 43.https://doi.org/10.1111/

j.1467-6486.2006.00625.x

कुक, डी. ए., एवं हटाला, आर. (2016). वैलिडेशन ऑफ एजुकेशनल असेसमेंट्स: अ प्राइमर फॉर सिम्युलेशन एंड बियॉन्ड. एडवांसेज़ इन सिम्युलेशन, 1(1), 31. https://doi.org/10.1186/s41077-016-0033-y

केमेंस, डी. एच., एवं मैकनीली, सी. एल. (2010). ग्लोबलाइज़ेशन एंड द ग्रोथ ऑफ इंटरनेशनल एजुकेशनल टेस्टिंग एंड नेशनल असेसमेंट. कंपेरेटिव एजुकेशन रिव्यू, 54(1), 5–25.https://doi.org/10.1086/648471

कोबो, एम., लोपेज़-हेरेरा, ए. जी., हेरेरा-विएद्मा, ई., एवं हेरेरा, एफ. (2011). साइंस मैपिंग सॉफ्टवेयर टूल्स: रिव्यू, एनालिसिस, एंड कूपरेटिव स्टडी अमंग टूल्स. जर्नल ऑफ द अमेरिकन सोसाइटी फॉर इंफॉर्मेशन साइंस एंड टेक्नोलॉजी, 62, 1382–1402. https://doi.org/10.1002/asi.21525

गोबर्ट, जे., पेड्रो, एम., रज़िउद्दीन, जे., एवं बेकर, आर. (2013). फ्रॉम लॉग फाइल्स टू असेसमेंट मेट्रिक्स: मेज़रिंग स्टूडेंट्स' साइंस इन्क्वायरी स्किल्स यूज़िंग एजुकेशनल डेटा माइनिंग. जर्नल ऑफ द लर्निंग साइंसेज़, 22, 521–563. https://doi.org/10.1080/10508406.2013.837391

ग्रेइफ, एस., वूस्टेनबर्ग, एस., मोल्नार, जी., फिशर, ए., फनके, जे., एवं सापो, बी. (2013). कॉम्प्लेक्स प्रॉब्लम सॉल्विंग इन एजुकेशनल कॉन्टेक्स्ट्स—समथिंग बियॉन्ड जी: कॉन्सेप्ट, असेसमेंट, मेज़रमेंट इनवेरिएंस, एंड कंस्ट्रक्ट वैलिडिटी. जर्नल ऑफ एजुकेशनल साइकोलॉजी, 105, 364-379.https://doi.org/10.1037/a0031856

चेंग, सी., वांग, एल., ज़ी, एच., एवं यान, एल. (2023). मैपिंग डिजिटल इनोवेशन: अ बिब्लियोमेट्रिक एनालिसिस एंड सिस्टमैटिक लिटरेचर रिव्यू. टेक्नोलॉजिकल फोरकास्टिंग एंड सोशल चेंज, 194,122706.https://doi.org/10.1016/j.techfore.2023.122706

जिया, एच., ली, एच., रोंग, वाई., जियांग, के., लियांग, एक्स., एवं ली, जी. (2024). नॉलेज मैपिंग ऑफ मैक्रोफैजेस इन ऑस्टियोपोरोसिस: अ बिब्लियोमेट्रिक एनालिसिस (1999–2023). ऑर्थोपेडिक सर्जरी, n/a-n/a.https://doi.org/10.1111/os.14159

ज़ुपिक, आई., एवं केटर, टी. (2015). बिब्लियोमेट्रिक मेथड्स इन मैनेजमेंट एंड ऑर्गनाइज़ेशन. ऑर्गनाइज़ेशनल रिसर्च मेथड्स, 18(3), 429–472. https://doi.org/10.1177/1094428114562629

टैन, एल., एवं डिंग, जे. (2015). द फ्रंटियर एंड एवोल्यूशन ऑफ द स्ट्रैटेजिक मैनेजमेंट थ्योरी. नानकाई बिज़नेस रिव्यू इंटरनेशनल, 6(1), 20–41. https://doi.org/10.1108/NBRI-09-2014-0036

नेरुर, एस., राशीद, ए. ए., एवं पांडेय, ए. (2016). साइटेशन फुटप्रिंट्स ऑन द सैंड्स ऑफ टाइम: एन एनालिसिस ऑफ आइडिया माइग्रेशन्स इन स्ट्रैटेजिक मैनेजमेंट. स्ट्रैटेजिक मैनेजमेंट जर्नल, 37(6), 1065–1084.https://doi.org/10.1002/smj.2377

पेज, एम. जे., मैकेंज़ी, जे. ई., बॉस्युत, पी. एम., बोट्रॉन, आई., हॉफमैन, टी. सी., मुलरो, सी. डी., शमसीर, एल., टेट्ज़लाफ, जे. एम., अक्ल, ई. ए., ब्रेनन, एस. ई., चाउ, आर., ग्लानविल, जे., ग्रिमशॉ, जे. एम.,ह्रोब्जार्ट्सन, ए.,लालु, एम. एम., ली, टी., लोडर, ई. डब्ल्यू., मेयो-विल्सन, ई., मैकडोनाल्ड, एस., मोहर, डी. (2021). द प्रिज्मा 2020 स्टेटमेंट: एन अपडेटेड गाइडलाइन फॉर रिपोर्टिंग सिस्टमैटिक रिव्यूज़. बीएमजे, 372, n71.https://doi.org/10.1136/bmj.n71

बेनेट, आर. ई. (2011). फॉर्मेटिव असेसमेंट: अ क्रिटिकल रिव्यू. असेसमेंट इन एजुकेशन: प्रिंसिपल्स, पॉलिसी एवं प्रैक्टिस, 18(1), 5–25. https://doi.org/10.1080/0969594X.2010.513678

ब्राइड्जेस, आर., हटाला, आर., ज़ेंदेजास, बी., एरविन, पी. जे., एवं कुक, डी. ए. (2015). लिंकिंग सिम्युलेशन- बेस्ड एजुकेशनल असेसमेंट्स एंड पेशंट-रिलेटेड आउटकम्स: अ सिस्टमैटिक रिव्यू एंड मेटा-एनालिसिस. अकैडेमिक मेडिसिन: जर्नल ऑफ द एसोसिएशन ऑफ अमेरिकन मेडिकल कॉलेजेज़, 90(2), 246–256.https://doi.org/10.1097/ACM.0000000000000549

ब्रूखार्ट, एस. एम. (2011). एजुकेशनल असेसमेंट नॉलेज एंड स्किल्स फॉर टीचर्स. एजुकेशनल मेज़रमेंट: इश्यूज़ एंड प्रैक्टिस, 30(1), 3–12. https://doi.org/10.1111/j.1745-3992.2010.00195.x

ब्रॉडस, आर. एन. (1987). टुवर्ड अ डेफिनिशन ऑफ "बिब्लियोमेट्रिक्स". सायंटोमेट्रिक्स, 12(5), 373–379. https://doi.org/10.1007/BF02016680

मैकबर्नी, एम. के., एवं नोवाक, पी. एल. (2002). व्हाट इज़ बिब्लियोमेट्रिक्स एंड व्हाय शुड यू केयर? प्रोसीडिंग्स. आईईईई इंटरनेशनल प्रोफेशनल कम्युनिकेशन कॉन्फ्रेंस, 108–11.https://doi.org/10.1109/IPCC.2002.1049094

मैक्कुलो, के. बी., फॉर्मिया, सी. एम., बर्ग, के. डी., बर्ज़िंस्की, जे. ए., कनिंघम, जे. एल., औ, एन. एन., रुडिस, एम. आई., स्टॉलिंग्स, जे. एल., एवं निकोल्सन, डब्ल्यू. टी. (2011). असेसमेंट ऑफ द फार्माकोजेनोमिक्स एजुकेशनल नीड्स ऑफ फार्मासिस्ट्स. अमेरिकन जर्नल ऑफ फार्मास्युटिकल एजुकेशन, 75(3), 51.https://doi.org/10.5688/ajpe75351

रेली, डी., न्यूमैन, डी. एल., एवं एंड्रयूज़, जी. (2019). जेंडर डिफरेंसेज़ इन रीडिंग एंड राइटिंग अचीवमेंट: एविडेंस फ्रॉम द नेशनल असेसमेंट ऑफ एजुकेशनल प्रोग्रेस (एनएईपी). अमेरिकन साइकोलॉजिस्ट, 74(4), 445–458. https://doi.org/10.1037/amp0000356

रेली, डी., न्यूमैन, डी., एवं एंड्रयूज़, जी. (2014). सेक्स डिफरेंसेज़ इन मैथेमैटिक्स एंड साइंस अचीवमेंट: अमेटा-एनालिसिस ऑफ नेशनल असेसमेंट ऑफ एजुकेशनल प्रोग्रेस असेसमेंट्स. जर्नल ऑफ एजुकेशनल साइकोलॉजी, 107. https://doi.org/10.1037/edu0000012

रोंडा-पूपो, जी., एवं गुएर्रास-मार्टिन, एल. (2012). डायनेमिक्स ऑफ द एवोल्यूशन ऑफ द स्ट्रैटेजी कॉन्सेप्ट 1962–2008: अ को-वर्ड एनालिसिस. स्ट्रैटेजिक मैनेजमेंट जर्नल, 33, 162–188.https://doi.org/10.1002/smj.948

लिन, आर. एल. (1994). परफॉर्मेंस असेसमेंट: पॉलिसी प्रॉमिसेस एंड टेक्निकल मेज़रमेंट स्टैंडर्ड्स. एजुकेशनल रिसर्चर, 23(9), 4–14. https://doi.org/10.2307/1177043

लीडेसडॉर्फ, एल. (2001). साइंटोमेट्रिक्स. इन एन. जे. स्मेल्सर एवं पी. बी. बाल्टेस (एडी.), इंटरनेशनल एनसाइक्लोपीडिया ऑफ द सोशल एवं बिहेवियरल साइंसेज़ (पृ. 13752–13755). परगामन. https://doi.org/10.1016/B0-08-043076-7/03200-9

वांग, एक्स., ज़ू, ज़., सू, एस.-एफ., एवं झोउ, डब्ल्यू. (2021). अ कॉम्प्रिहेन्सिव बिब्लियोमेट्रिक एनालिसिस ऑफ अनसर्टेन ग्रुप डिसीज़न-मेकिंग फ्रॉम 1980 टू 2019. इंफॉर्मेशन साइंसेज़, 547, 328–353.https://doi.org/10.1016/j.ins.2020.08.036

वान एक, एन. जे., एवं वॉल्टमैन, एल. (2007). वीओएस: अ न्यू मेथड फॉर विज़ुअलाइज़िंग सिमिलैरिटीज़ बिटवीन ऑब्जेक्ट्स. इन आर. डेकर एवं एच.-जे. लेंज़ (एडी.), एडवांसेज़ इन डेटा एनालिसिस (पृ. 299–306). स्प्रिंगर. https://doi.org/10.1007/978-3-540-70981-7_34

वान एक, एन. जे., एवं वॉल्टमैन, एल. (2010). सॉफ्टवेयर सर्वे: वोसव्युवर, अ कंप्यूटर प्रोग्राम फॉर बिब्लियोमेट्रिक मैपिंग. सायंटोमेट्रिक्स, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

वान एक, एन. जे., एवं वॉल्टमैन, एल. (2011). टेक्स्ट माइनिंग एंड विज़ुअलाइज़ेशन यूज़िंग वोसव्युवर (arXiv:1109.2058). arXiv. https://doi.org/10.48550/arXiv.1109.2058

वोगेल-वॉलकट, जे. जे., फियोरेला, एल., कार्पर, टी., एवं शैट्ज़, एस. (2012). द डेफिनिशन, असेसमेंट, एंड मिटिगेशन ऑफ स्टेट बोरडम विदिन एजुकेशनल सेटिंग्स: अ कॉम्प्रिहेन्सिव रिव्यू. एजुकेशनल साइकोलॉजी रिव्यू, 24(1), 89–111. https://doi.org/10.1007/s10648-011-9182-7

हेवर्ड, एल. (2015). असेसमेंट इज़ लर्निंग: द प्रपोज़िशन वैनिशेज़. असेसमेंट इन एजुकेशन: प्रिंसिपल्स, 22.https://doi.org/10.1080/0969594X.2014.984656

हॉल, सी. (2011). पब्लिश एंड पेरिश? बिब्लियोमेट्रिक एनालिसिस, जर्नल रैंकिंग एंड द असेसमेंट ऑफ रिसर्च क्वालिटी इन टूरिज़्म. टूरिज़्म मैनेजमेंट, 32, 16–27.https://doi.org/10.1016/j.tourman.2010.07.001

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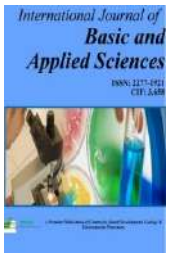

Research Paper

An Analysis of Trends and Cropping Patterns of leading Crops in Baghpat District, Uttar Pradesh

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ARTICLE DETAILS

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Key words:
Trend, Cropping Pattern, Analysis, Uttar Pradesh

ABSTRACT

This study analyzes the trends and cropping patterns of major crops in Baghpat District, Uttar Pradesh, with a focus on sugarcane, wheat, paddy, and oilseeds over the period from 2010–11 to 2020–21. Using secondary data sourced from government and research institutions, the study applies quadratic regression models to examine temporal changes in the area under cultivation for these crops. The analysis reveals that sugarcane remains the dominant crop in the district, maintaining a stable area of cultivation due to strong market demand and policy support. Wheat cultivation has experienced a slight decline, possibly due to soil fertility issues and competition from sugarcane. Paddy cultivation shows moderate fluctuations, reflecting its dependence on irrigation and climatic factors, while oilseeds exhibit the most significant growth, driven by technological advancements and market incentives. The results underscore the need for balanced crop diversification strategies and improved resource management to ensure sustainable agricultural development in the region.

1. Introduction

Agriculture is the backbone of the Indian economy, employing a large segment of the rural population and contributing significantly to national income. Among the various agro-climatic regions of India, Western Uttar Pradesh holds a pivotal position due to its fertile alluvial plains and favorable climatic conditions. The Baghpat district, situated in this region, is a prime agricultural zone known for cultivating a variety of major crops, especially sugarcane, wheat, and paddy. Understanding the trends and patterns of major crops in a region like Baghpat is crucial for agricultural planning, policy formulation, and ensuring sustainable rural livelihoods. Crop trends not only reflect the environmental suitability and technological adoption but also mirror the socio-economic priorities, market dynamics, and policy influences over time. The dominance of sugarcane in the district, while economically rewarding to some extent, also presents challenges such as monoculture dependency, fluctuating returns, and water resource stress.

This study aims to systematically analyze the cropping patterns and long-term trends of major crops in Baghpat district. It examines changes in area, production, and productivity across key crops over time, identifying factors influencing these shifts. By doing so, it provides valuable insights into the dynamics of local agricultural practices and the socio-economic and environmental implications they entail. The findings will contribute to a deeper understanding of regional agricultural development and offer evidence-based recommendations for promoting crop diversification and sustainable farming systems.

2. Data and Methodology

The present study is based on secondary data collected from authentic and reliable sources to analyze the trends and cropping patterns of major crops in Baghpat district, Uttar Pradesh. The data pertaining to area, production, and productivity of major crops such as sugarcane, wheat, paddy, and pulses were obtained for the period from 2009–10 to 2020–21. The primary sources of data include the District Statistical Office of Baghpat, Directorate of Economics and

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Statistics (Government of Uttar Pradesh), Agricultural Statistics at a Glance published by the Ministry of Agriculture and Farmers' Welfare, and various reports from the Indian Council of Agricultural Research (ICAR).

2.1 Comparative Analysis: Quadratic Trend Analysis

To study trends and patterns of major crops (Objective 2), quadratic regression was applied to time-series data on cultivated areas of sugarcane, wheat, paddy, and oilseeds from 2010-11 to 2020-21. Quadratic regression was selected based on its high coefficient of determination ((R^2)) and low Mean Square Error (MSE) compared to linear and exponential models.

2.3 Quadratic Trend Equation:

$$\mathbf{Y = a + bT + cT^2}$$

Where:

- Y : Dependent variable (crop area in hectares)
- T : Time index (0 for 2010-11, 1 for 2011-12, ..., 10 for 2020-21)
- a : Intercept (constant term)
- b : Linear coefficient
- c : Quadratic coefficient (controls curvature)

2.4 Model Selection Metrics:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

Where:

SSres : Sum of squared residuals = $\sum(Y - Y\hat{})^2$; SStot : Total sum of squares = $\sum Y - Y\hat{})^2$; Y : Observed value

$Y\hat{}$: Predicted value $Y\hat{}$: Mean of observed values

2.5 Mean Square Error (MSE):

$$MSE = \frac{1}{n} \hat{}(Y - Y\hat{})^{22}$$

Where:

- Y : Observed value; $Y\hat{}$: Predicted value; n : Number of observations

To achieve the objectives of the study, various quantitative and descriptive analytical techniques were employed. The trends and patterns of major crops were examined using the following methods:

3. Result and discussion

Table 1: Area (in Hectares) Cultivated for Major Crops in Baghpat District (2010-11 to 2020-21)

Year	Sugarcane	Wheat	Paddy	Oilseeds
2010-11	72,472	56,109	4,960	1,489
2011-12	72,427	56,113	5,088	1,537
2012-13	72,769	55,427	4,820	1,801
2013-14	77,554	53,668	5,168	1,986
2014-15	76,387	54,175	5,468	1,963
2015-16	76,387	54,175	5,468	1,963
2016-17	76,387	54,175	5,468	1,963
2017-18	76,387	54,175	5,468	1,963
2018-19	76,387	54,175	5,468	1,963
2019-20	76,387	54,175	5,468	1,963
2020-21	76,387	54,175	5,468	1,963

3.1 Results of Quadratic Regression Analysis

The quadratic regression analysis yielded trend equations, R^2, and MSE for each crop, as summarized in Table

3.2. The results confirm the suitability of the quadratic model in capturing non-linear trends in crop cultivation.

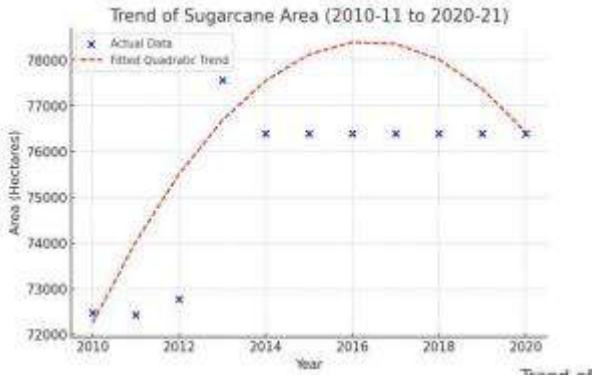
Table 2: Quadratic Regression Results for Major Crops in Baghpat District (2010-11 to 2020-21*)*

Crop	Quadratic Equation	R^2	MSE
Sugarcan	y=−151.3x2+1930.8x+72250 y = -151.3x^2 + 1930.8x + 72250	0.784	875,04
e	y=−151.3x2+1930.8x+72250	1	5
Wheat	y=−121.5x2+350.2x+55900 y = -121.5x^2 + 350.2x + 55900	0.837	144,41
	y=−121.5x2+350.2x+55900	6	5

Paddy	y=−12.7x2+150.5x+4900 y=−12.7x2+150.5x+4900	y = -12.7x^2 + 150.5x + 4900	0.854 5	13,156
Oilseeds	y=−7.8x2+110.2x+1500 1500 y=−7.8x2+110.2x+1500	y = -7.8x^2 + 110.2x +	0.933 4	3,745

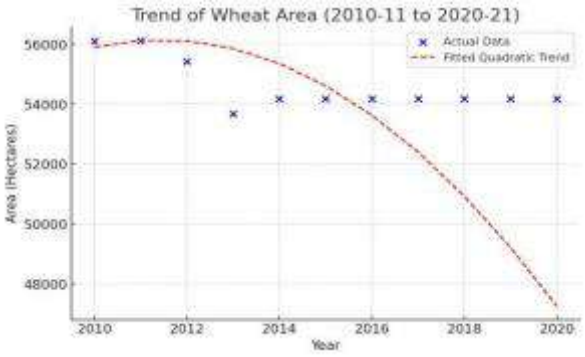
Sugarcane:

- **Trend**: The cultivated area increased from 72,472 ha in 2010-11 to a peak of 77,554 ha in 2013-14, then stabilized at 76,387 ha from 2014-15.
- **Model Fit**: An R^2 of 0.7841 indicates a moderate to strong fit, with an MSE of 875,045 reflecting reasonable accuracy given the large area values.
- **Interpretation**: The negative x^2 coefficient (-151.3) suggests a levelling off after an initial increase, likely driven by stable market demand, government support (e.g., minimum support prices), and assured water availability through irrigation facilities in
Baghpat fertile plains. The dominance of sugarcane underscores its economic importance in the region.



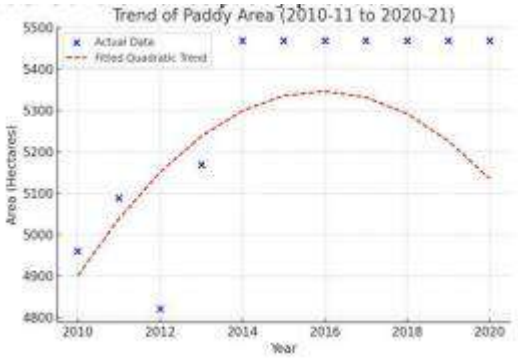
Wheat:

- **Trend**: The area peaked at 56,113 ha in 2011-12, declined to 53,668 ha in 2013-14, and stabilized at 54,175 ha thereafter (Figure 3.2).
- **Model Fit**: An R^2 of 0.8376 indicates a strong fit, with an MSE of 144,415.
- **Interpretation**: The negative x^2 coefficient (-121.5) reflects a slight declining trend, possibly due to agronomic constraints such as declining soil fertility, shifts to crop rotation, or farmer preferences for more profitable crops like sugarcane. Interventions in soil management are critical to sustain wheat cultivation.



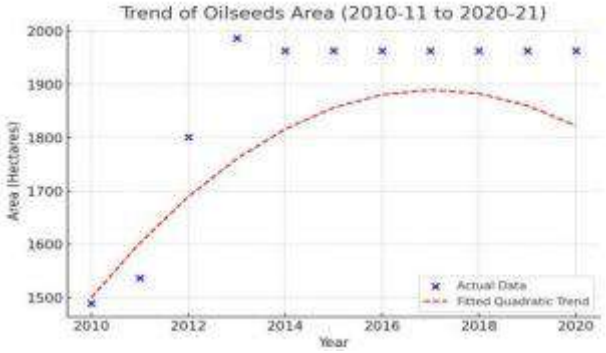
Paddy:

- **Trend**: The area fluctuated, peaking at 5,468 ha in 2014-15, then stabilizing (Figure 3.3).
- **Model Fit**: An R^2 of 0.8545 indicates a strong fit, with a low MSE of 13,156, reflecting high accuracy for the smaller area values.
- **Interpretation**: The negative x^2 coefficient (-12.7) suggests stabilization after initial growth, influenced by climatic variability (e.g., rainfall dependency) and policy support for rice cultivation. Improved irrigation could reduce fluctuations and enhance paddy production.



Oilseeds:

- **Trend**: The area increased from 1,489 ha in 2010-11 to 1,986 ha in 2013-14, then stabilized at 1,963 ha (Figure 3.4).
- **Model Fit**: An R^2 of 0.9334, the highest among all crops, indicates an excellent fit, with a low MSE of 3,745.
- **Interpretation**: The strong upward trend, moderated by a negative x^2 coefficient (- 7.8), reflects growing market demand, introduction of improved seed varieties, and favorable climatic conditions. Oilseeds show significant potential for expansion in Baghpat.



Discussion

The quadratic regression analysis reveals distinct trends and patterns in the cultivation of major crops in Baghpat District:

- **Sugarcane** remains the dominant crop, occupying the largest area (over 72,000 ha) and stabilizing at 76,387 ha, reflecting its economic viability and policy support. Its stability aligns with the study's focus on understanding factors driving sugarcane preference (Objective 3).
- **Wheat**, the second-largest crop, shows a slight declining trend, stabilizing at 54,175 ha. This decline may be linked to soil degradation or competition with sugarcane, warranting further investigation into agronomic factors.
- **Paddy** exhibits variability, stabilizing at 5,468 ha, with fluctuations tied to climatic and irrigation challenges. Its smaller area suggests a secondary role in the district's agriculture.
- **Oilseeds** demonstrate the strongest growth, stabilizing at 1,963 ha, with a high R^2 (0.9334) indicating consistent expansion driven by market and technological factors.

4. Conclusion

The trend analysis of major crops in Baghpat District between 2010-11 and 2020-21 reveals notable patterns:

- **Sugarcane** continues to dominate, showing a stable cultivation area post- 2013-14, supported by economic incentives and irrigation facilities.
- **Wheat** displays a slight decline and stabilization, hinting at competitive land use or soil constraints.
- **Paddy** shows modest fluctuations, stabilized after 2014-15, reflecting irrigation dependency.
- **Oilseeds** exhibit significant growth with stabilization at higher levels, driven by improved varieties and market demand.
-

5. References

Ansari, S., Khan, A., Ansari, S. A., Rehmat, A., Fateh, M., & Khan, M. S. (2023). Growth and Trend in Area, Production, and Yield of Wheat Crops in Uttar Pradesh: A Johansen Co-integration Approach. *Asian Journal of Agricultural Extension, Economics & Sociology, 41(2)*, 74–82.

Atla, J., Pokharkar, V. G., & Yadav, D. B. (2021). Trend analysis of area, production and productivity of paddy in India. *Journal of Pharmacognosy and Phytochemistry, 10(1)*, 362–364.

Fazal, S., & Vashishtha, D. (2022). Dynamics of Land Use Trends and Patterns in Uttar Pradesh: A Sectoral Perspective. *Journal of Land and Rural Studies, 10(2)*, 196–219.

Goyal, A. K., & Kumar, S. (2013). Agricultural production trends and cropping pattern in Uttar Pradesh. *International Journal of Agriculture Innovation and Research, 2(2)*.

International Sugar Organization. (2021). *World Sugarcane Production Trends and Factors Influencing Cultivation*. Retrieved from http://www.isosugar.org

Khan, A., Ansari, S. A., Ansari, S., Rehmat, A., Fatesh, M., & Khan, M. S. (2023). Growth and Trend in Area, Production, and Yield of Wheat Crops in Uttar Pradesh: A Johansen Co-integration Approach. *Asian Journal of Agricultural Extension, Economics & Sociology, 41(2)*, 74–82.

(Note: This is a duplicate of entry #1 and can be removed if only unique entries are needed.)

Kumar, S., Kumar, A., & Singh, M. (2016). Trend of Diversification in Farming System of Western Uttar Pradesh. *Annals of Horticulture, 9(1)*, 105–110.

Naidu, V. B., Sankar, A. S., & Leelavathi, C. (2014). Trends in area production and productivity of selected oilseed crops in Andhra Pradesh. *International Journal of Multidisciplinary Research and Development*.

Prasad, R. S. (1987). *A Study on Trend in Area, Production and Productivity of Pulses in Bihar*. Unpublished thesis, Rajendra Agricultural University.

Rahman, F., & Bee, N. (2019). Trends and pattern of sugarcane production in Shahjahanpur District, Uttar Pradesh: A geographical analysis. *Economic Affairs, 64(3)*, 537–545.

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Difference in Knowledge About Paddy Cultivation Among Trained And Untrained Respondents According to Their Different Categories of Personal And Socio-Economic Characteristics

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Abstract

The study analyzed the difference in knowledge regarding paddy cultivation among trained and untrained respondents across various personal and socio-economic categories. Among trained respondents, age showed minimal influence, except in knowledge of manures and fertilizers, while caste differences revealed that Scheduled Caste respondents possessed comparatively less knowledge due to weaker economic conditions and smaller landholdings. Education significantly influenced knowledge, with respondents educated up to Intermediate and above demonstrating higher awareness, especially in production technology, fertilizers, and post-harvest practices. Economic status also played a role, particularly in the adoption of improved implements. Training programmes, especially those conducted by KVK, effectively minimized knowledge gaps, except in practices requiring financial resources. In contrast, untrained respondents exhibited wider disparities, where older age groups had higher knowledge than younger ones. Caste and education differences were significant, with educated respondents showing superior understanding. Overall, training emerged as a key factor in bridging knowledge disparities across socio-economic categories.

Keywords: Knowledge level; Trained and untrained respondents; Socio-economic characteristics; Paddy cultivation; Krishi Vigyan Kendra (KVK); Agricultural training programmes, Technology adoption.

Introduction

Paddy is the staple food of India and holds immense importance in the national economy, yet a large proportion of paddy farmers still live below the poverty line. To address food security challenges, high-yielding varieties have been developed, making India the world's second-largest rice producer after China, contributing nearly 25 per-cent of global rice production. Being the staple for over half of the world's population, paddy cultivation is vital not only for food security but also for rural livelihoods. Knowledge plays a vital role in improving agricultural productivity, particularly in the scientific management of paddy cultivation. However, variations in knowledge often arise due to differences in personal and socio-economic characteristics of farmers. Training programmes, such as those conducted by Krishi Vigyan

Kendras (KVKs), aim to bridge these gaps by providing scientific awareness and practical skills. To assess their effectiveness, it is important to compare the knowledge of trained and untrained respondents across different categories such as age, caste, education, economic status, and social status. Evidence from the study reveals that trained respondents showed relatively uniform knowledge across age groups, while caste and education created noticeable differences. Similarly, economic status influenced awareness of improved implements and costly practices. In contrast, untrained respondents displayed wider disparities, with older, educated, and economically better-off groups having greater knowledge. Thus, training emerges as a crucial factor in minimizing socio-economic disparities in agricultural knowledge. Keeping this view the present investigation was conducted with the single specific objective.

To find out the difference in Knowledge About Paddy Cultivation Among Trained And Untrained Respondents According to Their socio Personal and Socio-Economic Characteristics.

Research Methodology :

Presently, 731 Krishi Vigyan Kendras (KVKs) are functioning in the country, of which 89 are located in Uttar Pradesh. For this study, only one KVK, Sultanpur, was selected purposively. The district Sultanpur consists of 22 Community Development (CD) blocks and 2533 villages. Among these, KVK Sultanpur has adopted 8 blocks and two CD blocks, namely Dubeypur and Lamuha, were randomly chosen for the study. To select villages, a list of adopted villages under both blocks was obtained from KVK Sultanpur. From this list, four villages were randomly selected from each block where training programmes on paddy cultivation had been conducted. For comparison, eight adjoining villages were also selected as non-participant villages, resulting in a total of sixteen villages. In view of the objectives, two categories of respondents were selected—trained and untrained farmers of KVK training programmes on paddy cultivation. The respondents were chosen through proportionate random sampling. A complete list of trained and untrained farmers was prepared from each village. In cases where the number of trained farmers in a village was 35 or more, 25 percent of them were selected as respondents, while in villages with fewer than 35 trained farmers, 35 percent were included. For untrained farmers, respondents were selected in equal proportion from adjoining villages. Independent variables included age, caste, education, size of holdings, farm power, irrigation, cropping pattern, social participation, social status, economic status, and overall socio-economic status. The dependent variables were knowledge of paddy cultivation practices. Primary data were collected by the researcher himself using a structured interview schedule prepared on the basis of standardized scales. Rapport was first established with the respondents to ensure accuracy and reliability of responses. The collected data were classified, tabulated, and analyzed in accordance with the objectives and hypotheses of the study. Appropriate statistical tools such as frequency distribution, percentage, mean, and **'t' test** were applied for analysis and interpretation.

Statistical Procedure :

For the analysis of data, appropriate statistical tools were applied to ensure meaningful interpretation. Frequency distribution and percentage were used to determine the distribution of respondents into different categories and to standardize responses for comparison. Arithmetic mean was calculated to measure the central tendency of observations, representing the average of values obtained. The **'t' test** was employed to examine the significance of differences between the mean scores of two samples, thereby identifying whether they belonged to the same population or differed significantly. This test was particularly useful in comparing trained and untrained respondents regarding knowledge and adoption of paddy cultivation

practices. In addition, the **measurement of socio-economic status** was carried out using a standardized scale to categorize respondents based on their personal and socio-economic characteristics. These statistical tools together provided a reliable basis for analysis, interpretation, and drawing valid conclusions.

RESULTS AND DISCUSSION:

Table - 1 shows the difference in knowledge among trained respondents according to their different categories of six personal and socio-economic characteristics. It was found that there was no significant difference in knowledge about paddy cultivation among different age categories of respondents except middle and old aged respondents in respect of manures/fertilizers. This shows that age had no significant effect on the knowledge of trained respondents.

Table - 1 Difference in knowledge among trained respondents according to their different categories of personal and socio-economic characteristics

Sl. No.	Differences in Categories	Difference in Knowledge ('t' value)					
		PP	M/F	PPM	I/I	PHT	Total
1.	Age						
a.	Young Vs Middle	0.301	0.900	0.700	1.131	1.000	1.098
b.	Young Vs Old	0.700	0.550	0.400	0.717	1.000	0.342
c.	Middle Vs Old	0.650	2.279*	0.600	1.006	1.000	1.255
2.	Caste						
a.	SC Vs OBC	-2.412*	1.018	1.921	1.909	1.000	1.962
b.	SC Vs Gen.	-2.800*	2.635*	3.101*	2.744*	1.000	3.002*
c.	Gen. Vs OBC	0.402	1.947	0.702	0.526	1.000	1.005
3.	Education						
a.	Illi. Vs JHS	1.363	1.041	0.539	0.179	1.000	0.713
b.	Illi. Vs HS	0.465	0.043	0.147	0.126	0.655	0.125
c.	Illi. Vs Inter & above	0.667	0.698	0.009	0.369	0.655	0.419
d.	JHS Vs HS	0.356	0.941	0.932	0.037	0.100	0.636
e.	JHS Vs Inter & above	3.465*	3.415*	1.391	0.299	1.000	2.242*
f.	HS Vs Inter & above	1.102	0.724	0.212	0.667	6.513*	0.600
4.	Social Status						
a.	Low Vs Medium	1.116	0.662	0.994	0.607	1.000	0.746
b.	Medium Vs High	1.223	1.919	0.703	1.002	0.655	1.395
c.	Low Vs High	0.561	1.807	0.606	0.687	1.000	1.052
5.	Economic Status						
a.	Low Vs Medium	0.049	1.378	0.204	1.677	0.655	0.646
b.	Low Vs High	0.433	0.871	0.614	3.373*	1.000	0.700
c.	Medium Vs High	1.115	0.550	0.748	1.377	1.000	0.143

6.	SocioEconomic Status						
a.	Low Vs Medium	0.605	0.166	0.378	1.921	0.015	1.386
b.	Low Vs High	0.788	0.515	0.736	1.470	1.000	1.508
c.	Medium Vs High	1.081	1.682	0.446	1.269	1.000	0.266

PP - Preliminary Preparation; M/F - Manures/Fertilizers; PPM - Plant Protection Measure; I/I - Irrigation/Implements; PHT - Post Harvest Technology

* - Significant at 5 per cent level of probability

In case of caste categories, significant difference in knowledge of scheduled caste respondents was found with other backward caste in the knowledge about preliminary preparation and with general caste category in all the practices of paddy cultivation. It may be concluded that the respondents of scheduled caste had less knowledge on scientific paddy cultivation as compared with other caste categories. This trend may be because of poor economic condition and small land holdings.

This table, further highlights that the significant difference in knowledge on production technology and manures/fertilizers as well as overall knowledge about paddy cultivation between the respondents who had education upto Junior High School & Intermediate and above. The knowledge on post harvest technology was found significantly different between the respondents who had education upto High School & Intermediate and above. The significant difference in knowledge on improved implements was also found between the respondents of low and high economic status.

It is observed from the table that the training programme of KVK has significantly reduced the gap in knowledge among different categories of personal and socio-economic status of the respondents were found only in those practices which requires the financial obligations.

The Table - 2 reveals the difference in knowledge among the untrained respondents according to their different categories of personal and socio-economic characteristics. It was found that old age categories of respondents had significant difference in knowledge with young and middle age categories in respect of all the practices of paddy cultivation except post-harvest technology. It is concluded that old age categories had significantly, high knowledge on paddy cultivation as compared with other age categories.

Table - 2 Difference in knowledge among untrained respondents according to their different categories of personal and socio-economic characteristics

Sl. No.	Differences in Categories	Difference in Knowledge ('t' value)					
		PP	M/F	PPM	I/I	PHT	Total
1.	Age						
a.	Young Vs Middle	1.475	1.845	1.139	1.678	1.435	1.751
b.	Young Vs Old	3.195*	4.076*	3.835*	3.672*	0.655	4.057*
c.	Middle Vs Old	3.522*	3.748*	3.960*	2.337*	1.435	4.237*
2.	Caste						
a.	SC Vs OBC	1.974	0.287	3.527*	2.605*	1.200	2.137*
b.	SC Vs Gen.	3.452*	2.862*	6.758*	5.438*	0.359	5.012*
c.	Gen. Vs OBC	1.070	2.752*	4.337*	2.828*	1.300	2.883*

3.	Education						
a.	Illi. Vs JHS	2.500*	1.562	4.181*	2.475*	1.100	3.253*
b.	Illi. Vs HS	1.494	1.712	4.459*	2.521*	1.800	3.026*
c.	Illi. Vs Inter & above	5.317*	5.488*	8.192*	6.507*	0.033	7.717*
d.	JHS Vs HS	0.901	0.367	1.445	0.078	0.655	0.274
e.	JHS Vs Inter & above	2.985*	3.953*	4.188*	3.145*	1.230	4.094*
f.	HS Vs Inter & above	3.782*	3.194*	2.006*	3.017*	1.400	3.425*
4.	Social Status						
a.	Low Vs Medium	5.951*	0.982	1.948	1.675	1.430	0.009
b.	Medium Vs High	0.741	1.347	0.832	0.101	1.210	0.868
c.	Low Vs High	0.079	1.149	0.615	0.410	0.064	0.878
5.	Economic Status						
a.	Low Vs Medium	0.913	0.358	1.365	1.067	1.800	1.332
b.	Low Vs High	3.984*	3.212*	3.389*	3.025*	1.200	4.155*
c.	Medium Vs High	4.076*	3.624*	3.619*	2.969*	0.415	4.037*
6.	Socio-Economic Status						
a.	Low Vs Medium	2.714*	0.581	4.699*	4.769*	1.400	3.835*
b.	Low Vs High	5.114*	4.210*	8.347*	6.156*	0.140	6.949*
c.	Medium Vs High	3.506*	3.827*	4.517*	2.238*	1.500	4.019*

PP - Preliminary Preparation; M/F - Manures/Fertilizers; PPM - Plant Protection Measure; I/I - Irrigation/Implements; PHT - Post Harvest Technology

* - Significant at 5 per cent level of probability

In view of the difference in knowledge according to their caste categories. It was found that knowledge about plant protection measure, irrigation/implements as well as overall knowledge of paddy cultivation were found significantly difference among all the three caste categories with each other. Further, the knowledge about manures/fertilizers and general caste categories was found significantly different with scheduled caste and other backward caste categories.

As far as the education level of the respondents was concerned, significant difference in knowledge about plant protection measure, irrigation/implements and overall practices of paddy cultivation was found on all the educational categories of the respondents with each other except the knowledge among the respondents who had education upto to High School and Junior High School was found to be at par. The difference in knowledge about preliminary preparation and manures/fertilizers among the respondents who had education upto Intermediate & above was found significantly higher than the respondents who were illiterate and education upto Junior High School and High School. It ass also observed that the knowledge among educated respondents is higher than other less educated respondents.

In case of economic status of the respondents, significant difference in knowledge about all the practices of paddy cultivation except post-harvest technology among high economic status was found with low and medium economic status. It clearly reveals that the respondents of high economic status had more knowledge as compared with the respondents of other economic status.

As far as the knowledge among the respondents of different categories of socio-economic status was concerned, the significant difference in knowledge about all the practices of paddy cultivation except post-harvest technology and among three categories of respondents with each other.

Conclusion:

The study highlights significant differences in knowledge of paddy cultivation among trained and untrained respondents across personal and socio-economic categories. Training programmes organized by KVK played a vital role in minimizing knowledge gaps, particularly in technical and scientific practices, though disparities remained in areas requiring financial investment. Among trained farmers, age showed minimal influence, while caste, education, and economic status significantly shaped knowledge levels. In contrast, untrained respondents displayed wider variations, with older, educated, and economically better-off farmers possessing higher awareness. Overall, training emerged as an effective tool for bridging knowledge disparities and promoting scientific cultivation practices.

References

1. Ghosh, P. K., & Pandey, K. N. (2003). *Impact of Training on Knowledge of Farmers about Improved Rice Cultivation Technologies.* Indian Journal of Extension Education, 39(1-2), 108-110.
2. Naberia, S., Gautam, U. S., & Gupta, Aroop Kumar. (2011). *Socio-Economic Factors Influencing Adoption of Low Cost Agricultural Technologies.* Indian Journal of Extension Education, 47(3&4), 115-119.
3. Yadav, Shailu; Rai, D. P.; Singh, Y. K.; Misra, Abhishek. (2025). *Exploring the Association of Socio-Economic Factors with Knowledge of Eco-Friendly Farming Practices among Vegetable Growers in Madhya Pradesh, India.* Journal of Experimental Agriculture International, 47(2): 132-137.
4. Smriti Yadav & Vijay Kumar Yadav. (2024). *The Socio-Economic Factors Affecting Farmers Access to Agricultural Information.* Journal of Scientific Research and Reports, 30(5), 564-569.
5. Dash, Samir Ranjan; Mukhopadhyay, Sidhartha Dev; Mishra, Prasanna Jit; Swain, Susanta Kumar. (2022). *Identifying and Understanding Factors Influencing the Knowledge Level of Farmers in Watershed Development Programme Using Principal Components Analysis.* Asian Journal of Agricultural Extension, Economics & Sociology, 40(10): 893-908.
6. SARADA, O. (2019). *Effect of Training Programmes on Knowledge Levels of Paddy and Cotton Farmers in Prakasam District of Andhra Pradesh.* The Journal of Research, PJTSAU, 47(1).
7. Dash, Abhisek & Jahanara. (2023). *A Study on the Knowledge about Information and Communication Technology Tools of Paddy Growers in the Nuapada District of Odisha.* Asian Journal of Agricultural Extension, Economics & Sociology, 41(6): 153-61.

वरूणा नदी : "कृषि मत्स्य पालन और लोगों के आजीविका के लिए वरदान"

डॉ० मनोज कुमार सिंह
असिस्टेंट प्रोफेसर
भूगोल विभाग
उदय प्रताप स्वापशारणी कालेज
वाराणसी

सारांश :

भारत जैसे उष्ण और मौसमी वर्षा वाले देश में नदियों का विशेष महत्व है। इन्ही नदियों के किनारे भारतीय सभ्यता का विकास हुआ है आज भी देश की समृद्धि में इनका विशिष्ट योगदान है। नदी जल के संरक्षण एवं सदुपयोग से केवल बाढ़ सूखा आदि प्राकृतिक आपदाओं का स्थाई समाधान ढूढा जा सकता है। त्वरित संभावित जल संकट से बचा जा सकता है। वर्तमान में सम्पूर्ण भारत में 14 बडी नदियाँ 200 मध्य स्तर की नदियाँ तथा 20 हजार छोटी नदियों का जल पूरे भारत के अपवाह तन्त्र में महत्वपूर्ण भूमिका का निर्वाह करती है। संचित जल भाग के द्वारा भूमि की समृद्धि में वृद्धि होती है।

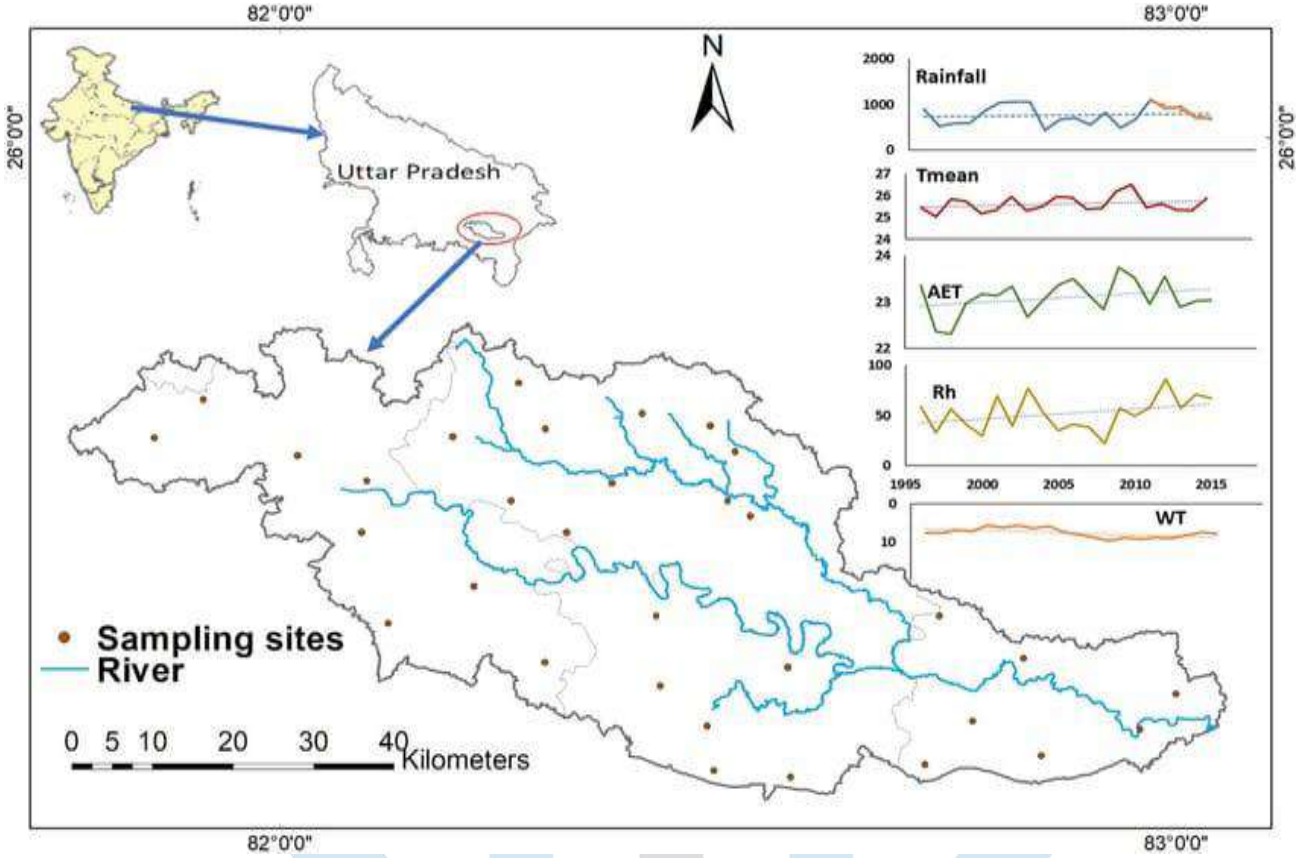
1. *नदियों से पानी पीने के लिए।*
2. *खेती के लिए उपजाऊ मिट्टी की फसलों को संचित करने के लिए।*
3. *नदी से जल प्राप्त होता है।*
4. *अवसाद की नदियों का इस्तेमाल जल परिवहन के लिए किया जाता है।*
5. *नदियाँ पर्यावरण निस्तारण में भी मदद करती है।*

अनेक नदियाँ धार्मिक और सांस्कृतिक महत्व की है। उसी नदियों में उत्तर भारत के जीवन की सभ्यता, सांस्कृतियों, आर्थिक उन्नति के लिए पहचान रखने वाली नदी गंगा की सहायक एक छोटी नदी वरूणा नदी का प्रभाव महत्व पूर्ण हैं। वर्तमान में वरूणा नदी जीवन दायिनी से मुक्तिदायनी नदियों के रूप में भी अपनी पहचान रखती है। अनेक गाँव वरूणा नदी के दोनों तटों पर बसे हुए है। सभी गाँव में कृषि उत्पादन और मत्स्य उत्पादन एवं पीने के पानी की उपलबधता पर्याप्त मात्रा में नदी उपलब्ध करता है। साथ ही साथ जल संचयन की प्रवृत्ति भी इस नदी द्वारा होता रहता है। जो क्षेत्र विशेष के मैदानी भागों में आर्थिक उन्नति, कृषि उत्पादन, सिंचित क्षेत्र के लिए, सांस्कृतिक विरासत, मत्स्य उत्पाद के लिए महत्वपूर्ण रही है।

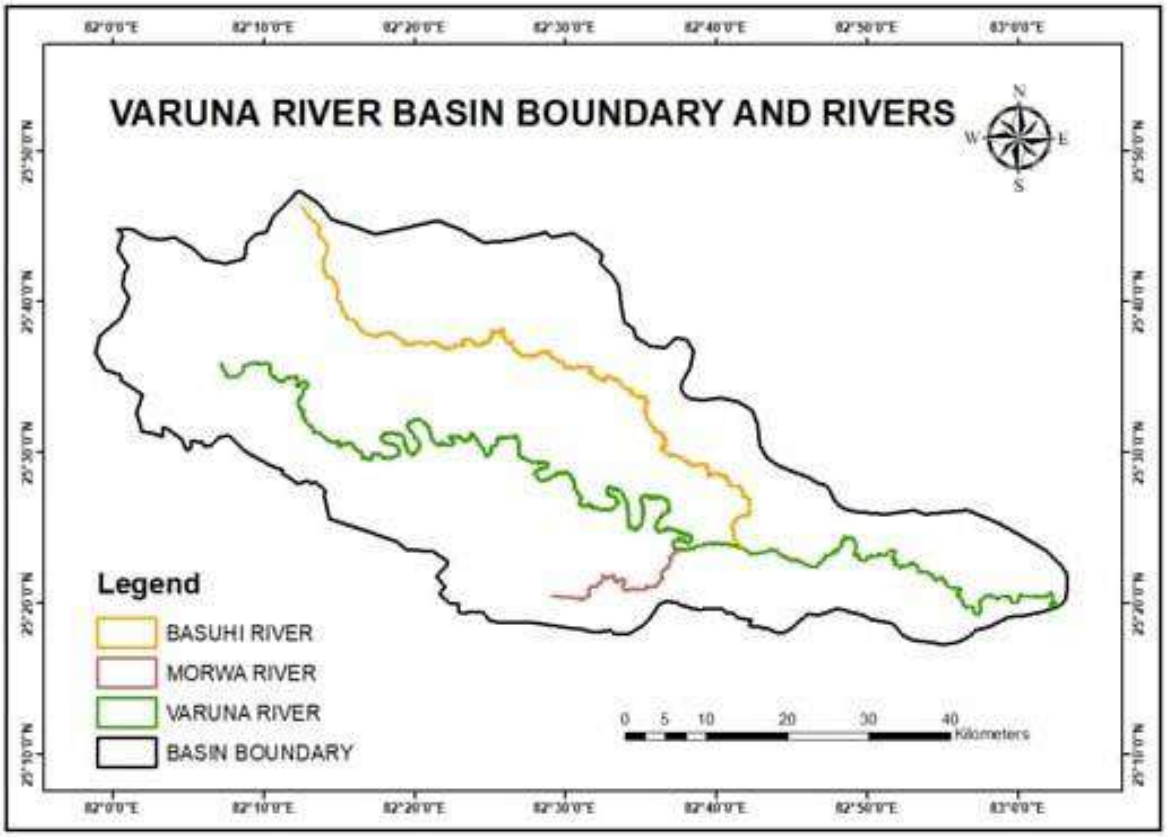
प्रस्तावना :

भारत की संस्कृति, कृषि और स्थानीय लोगों की आजीविका में नदियों का विशेष योगदान है। वरूणा नदी की भौतिक संपदा के साथ–साथ विशाल मैदान के निर्माण में सहायक रही है। कभी–कभी नदियों द्वारा क्षेत्र में साम्राज्य की सीमा का निर्धारण हुआ है। वरूणा नदी भारत की पवित्र नदी गंगा की सहायक छोटी सी वितरिका नदी के रूप में (प्रयागराज) के फूलपुर तहसील की सीमा पर जनउझ ताल के मैलहन झील $25^0 3'29''$ से $25^0 19'46''$ उत्तरी अक्षांश से 83^0 से $83^0 2'40''$ पूर्वी देशांतर के मध्य से निकलती है जिसकी कुल लम्बाई 202 किमी० है। जो अपने टेड–मेडे रास्ते बनाती है। इस नदी के दोनो तरफ गाँव का अध्यावस अति प्राचीन काल से है। वरूणा नदी के क्षेत्र में अनेक गाँव चिरागी एवं गैर चिरागी गाँव है। जो विशेष आपदा के कारण अपने क्षेत्र में परिवार्तित होते रहते है। वरूणा नदी वाराणसी जौनपुर सीमा पर सराया गाँव के पास वाराणसी जनपद में मिलती है। जहां भद्रकाली मंदिर प्रसिद्ध है। वहॉ सम्राट विक्रमदित्य के सैन्य छावनी (किला के पास) है। वाराणसी के पिण्डरा, बडागांव, हरहुआ, सेवापुरी, आराजी लाइन एवं काशी विद्यापीठ विकास खण्ड वाराणसी सदर के भू–भाग में 102 किमी०

बहती है। वरूणा की सहायक नदी बसुही नदी वाराणसी व जौनपुर की जनपद सीमा बनाती हुई वरूणा में मिल जाती है।



अपवाह तंत्र : वाराणसी जनपद में वरूणा नदी के प्रवेश मार्ग के बाद बायें किनारे पर विकासखण्ड : बड़ागाँव, पिण्डरा, हरहुआ तथा दायें किनारे पर सेवापुरी, आराजी लाइन, काशी विद्यापीठ, कुल छः विकासखण्ड के लिए अधिक महत्वपूर्ण है। जिसमें स्थानीय छोटी–छोटी जल वितरिकाएं नदी में मिलती है।


VARUNA RIVER BASIN BOUNDARY AND RIVERS
N
S
E
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Legend
BASUHI RIVER
MORWA RIVER
VARUNA RIVER
BASIN BOUNDARY
0 5 10 20 30 40
Kilometers
82°0'0"E
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82°30'0"E
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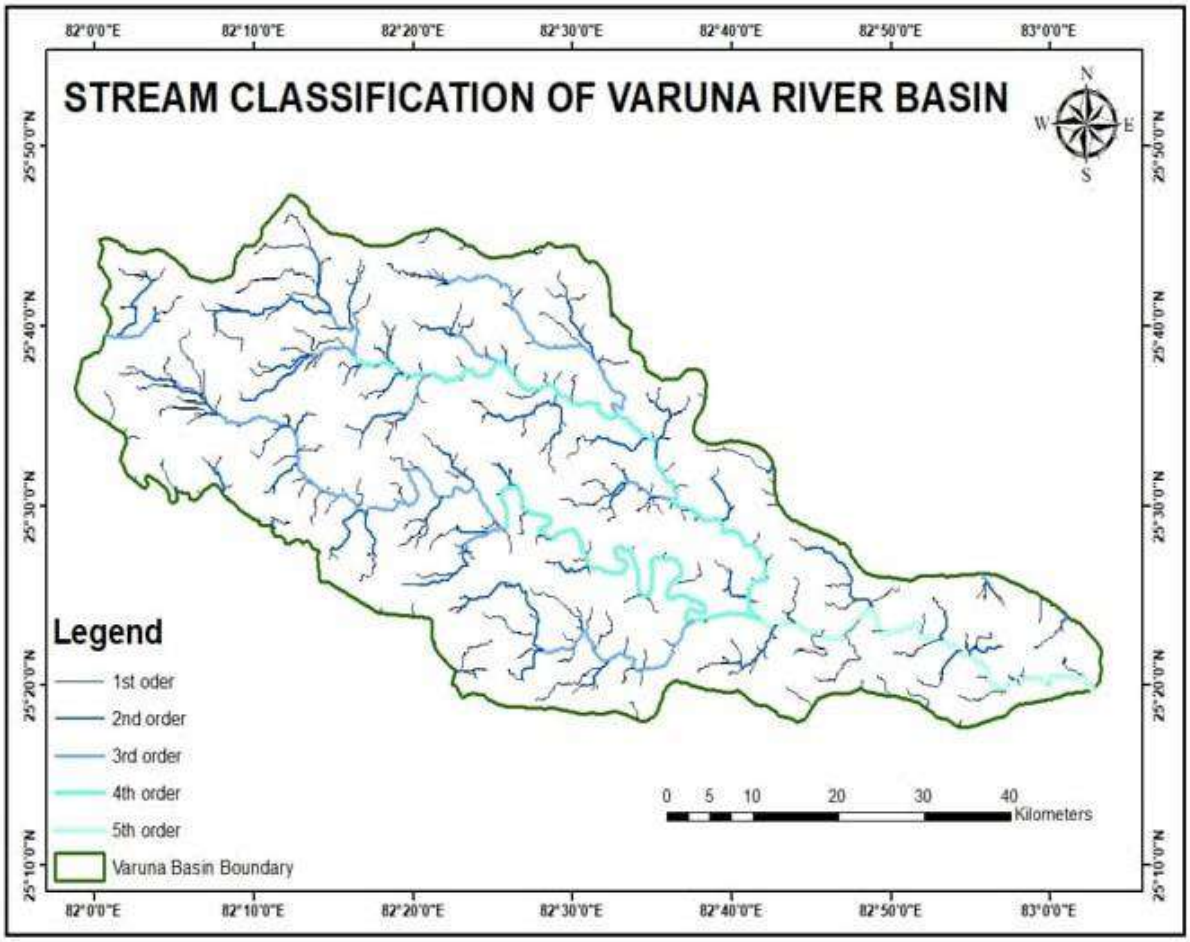
STREAM CLASSIFICATION OF VARUNA RIVER BASIN
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1st oder
2nd order
3rd order
4th order
5th order
Varuna Basin Boundary
0 5 10 20 30 40
Kilometers
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82°10'0"E
82°20'0"E
82°30'0"E
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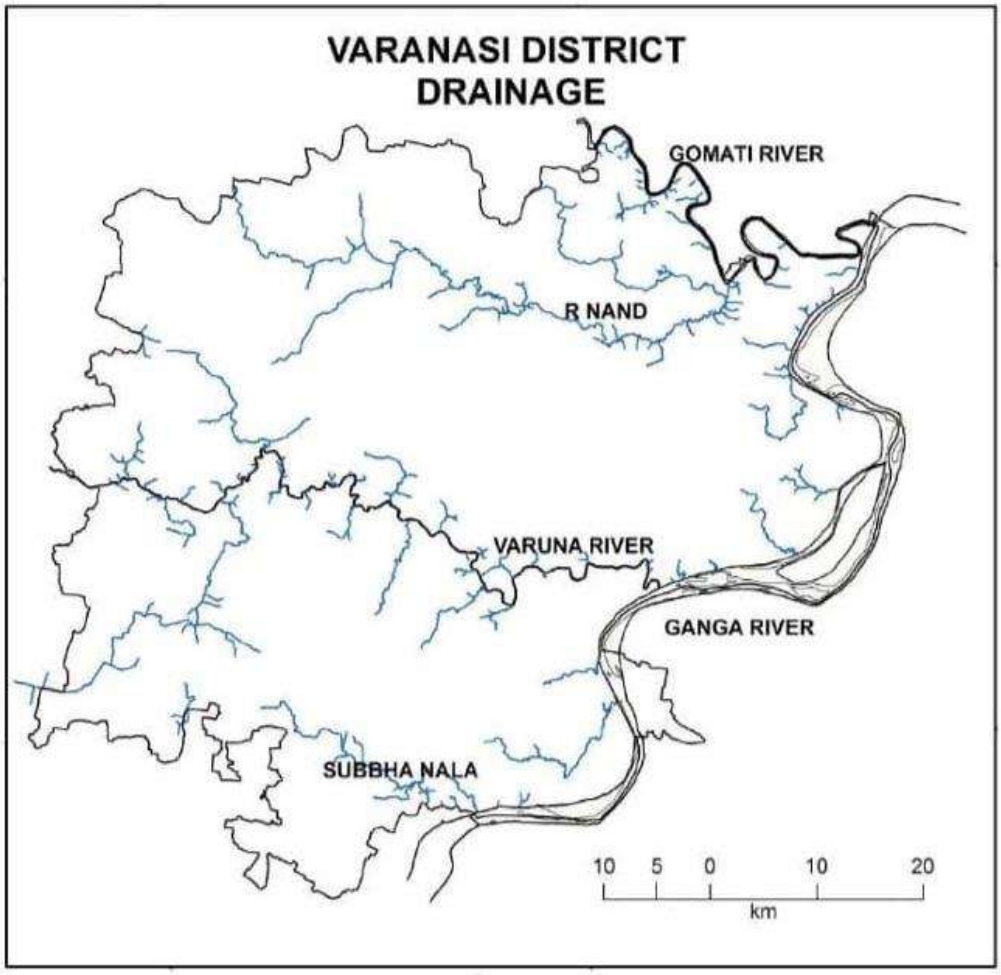
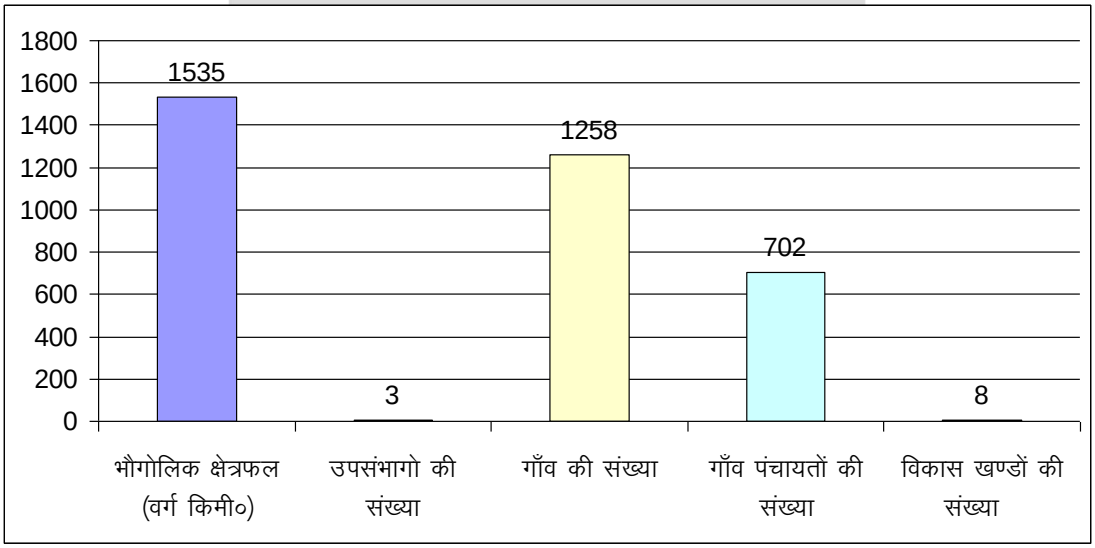
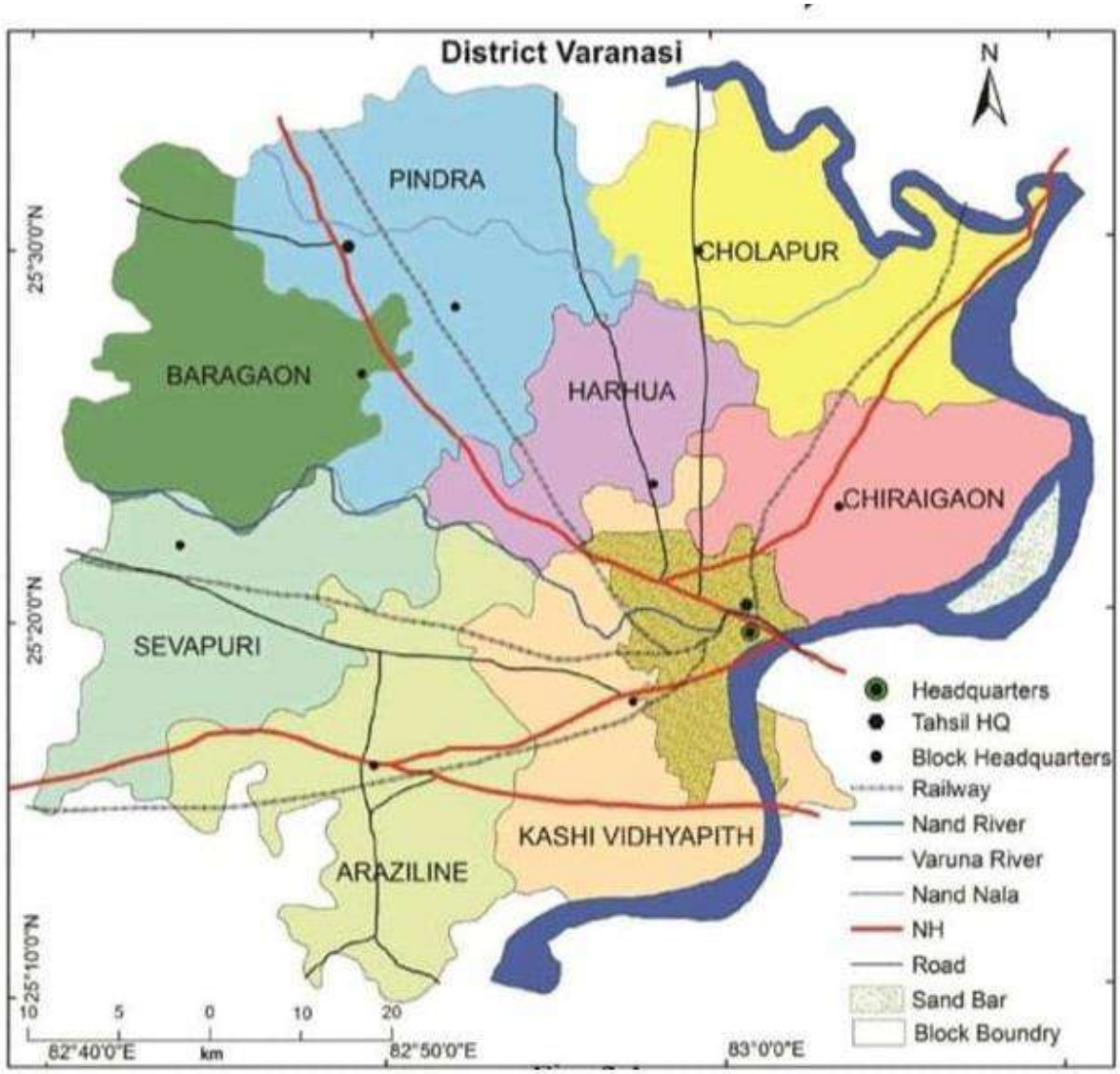


भौगोलिक विशेषताएँ

भौगोलिक क्षेत्रफल (वर्ग किमी०)	1535
उपसंभागो की संख्या	3
गाँव की संख्या	1258
गाँव पंचायतों की संख्या	702
विकास खण्डों की संख्या	8





कृषि – वाराणसी जनपद का कृषि फसल के उत्पादन में महत्वपूर्ण स्थान है। अन्न एवं मानसूनी जलवायु के कारण कृषि फसलों को खरीफ, रवी एवं जायद में विभाजित किया जाता है। जिसमें मिश्रित कृषि की व्यवस्था पायी जाती है। वरूणा नदी का मैदानी क्षेत्र अपने उपजाऊपन के लिए प्रसिद्ध है इस क्षेत्र की मिट्टी सामान्यतः चिकनी, हल्की दोमट, पाट में नाइट्रोजन युक्त मिट्टी पाई जाती है। बांगर, खादर युक्त मिट्टी की विशेषता है। जिसमें खाद्यान की फसलों–गेहूँ, धान, ज्वार, बाजरा, जौ मक्का आदि फसलों की कृषि करते है। दलहन की फसल में अरहर, मूंग, ऊर्द, चना मटर, मसूर, तिलहन की फसल में सरसों, तीसी, तिल, सूर्यमुखीं कृषि के नकदी फसलों मे गन्ना, सनई, पटसन, फूल की कृषि, सब्जी की कृषि में–आलू, प्याज, लहसुन आदि एवं हरी सब्जी की कृषि बडे पैमाने पर किया जाता है। चारा की फसल – वासनीन बजडा एवं लोविया घास की बुआई की जाती है। कृषि में फसल उत्पादन एवं पशुधन की विशेषता होती है। जो स्वेच्छा से अपने सामर्थ्य के अनुसार कृषक द्वारा किया जाता है। प्रायः सभी गाँवों में पशुपालन, बकरी एवं भेड पालन किया जाता है। प्रत्येक गाँव में दुग्ध उत्पादन छोटे से बडे स्तर पर (गोशाला एवं डेयरी उद्योग) के रूप में किया जाता है। जिससे दुग्ध उत्पादन शहर की आवश्यकता की पूर्ति के लिए करते है। भौगोलिक क्षेत्र 152678 हे0 के 62.32% भू–भाग पर खेती की जाती है। शुद्ध बोई जाने वाली फसल 95164 हेक्टयर भूमि में से 79983 हेक्टेयर भूमि सिंचित है। जिले में खरीफ की

मध्य फसलों में धान, ज्वार, बाजरा, तिल व अरहर तथा रवी की प्रमुख फसलों गेहूँ, जौ, चना, राई/सरसों तीसी है इस जनपद का जोते का आकार छोटा होने तथा सिचाई के साधनों के कारण किसान तीन फसल की कृषि करते है। लेकिन कृषि उत्पादकता कम है। जनपद में मुख्य रूप से मटियार पाठ, दोमट एवं बलुई दोमट मिट्टी के कारण क्षेत्र का विकास हुआ है। जो आजीविका के मुख्य साधन है।

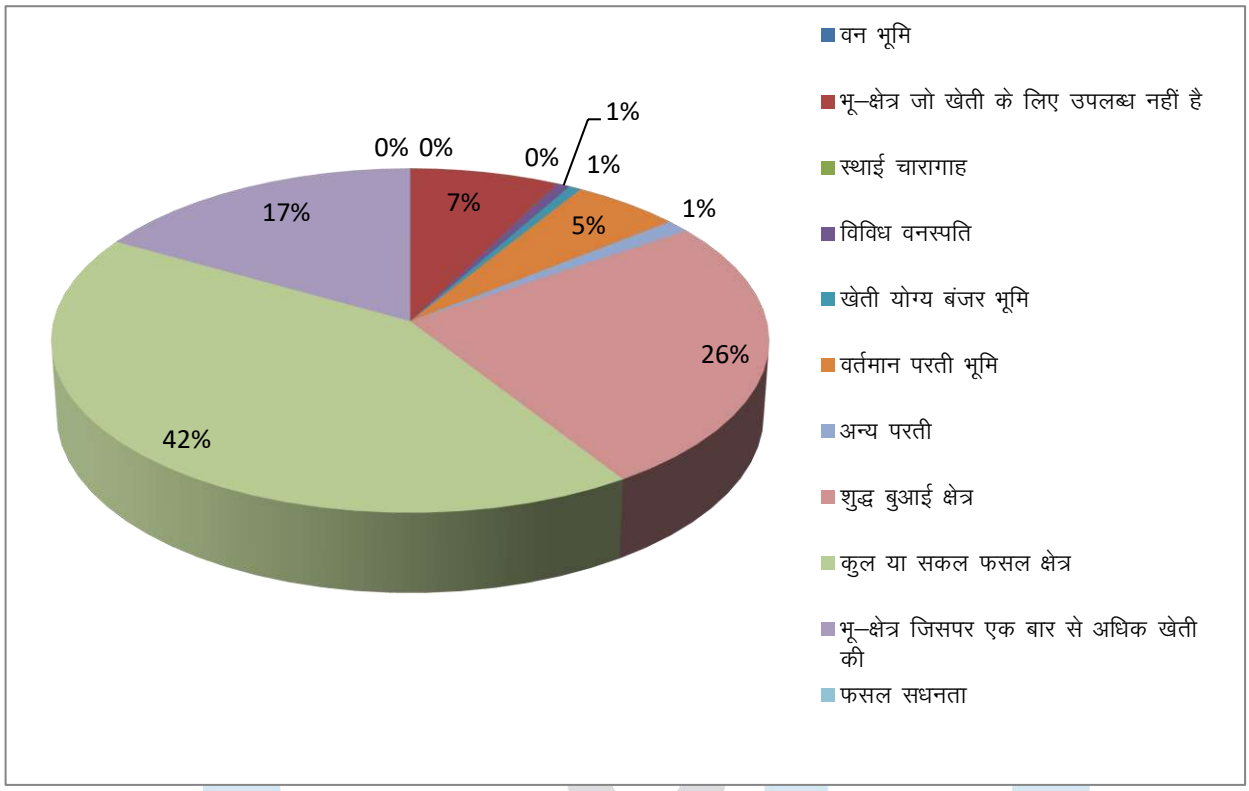
वरूणा नदी के प्रवाह मार्ग में विकास खण्ड (वाराणसी) के सम्पूर्ण क्षेत्रफल व गाँव :–

क्र. स.	विकास खण्ड	गाँवो की सं.	क्षेत्रफल किमी.	क्षेत्रफल हेक्टेयर	कुल जन सं.	जन सं. पुरूष	महिला	कृषिक		
								कुल कृषक	पुरूष	महिला
वा.	वाराणसी	1258	1535	152678	3676841	1921857	1754984	151854	116682	35172
1.	पिण्डरा	190	221.91	2219126	275679	139511	136168	24529	17722	6807
2.	बड़ागांव	138	172.43	17221.68	232754	116704	116055	18315	13724	4591
3.	हरहुआ	186	137.12	13712.00	271005	141518	129487	14816	11235	3581
4.	सेवापुरी	204	169.16	16916.12	239392	121016	113876	17546	14209	3337
5.	आ. ला.	184	223.86	22305.70	361482	189054	172428	23917	18336	5581
6.	का. वि.	163	163.47	16347.07	456326	240403	215923	12500	9918	2682
		1065	108715	108714.83	1831643	948206	883937	111623	85144	26579

स्रोत – सांख्यिकीय पत्रिका (उ0प्र0) के वाराणसी 2000 – 2011

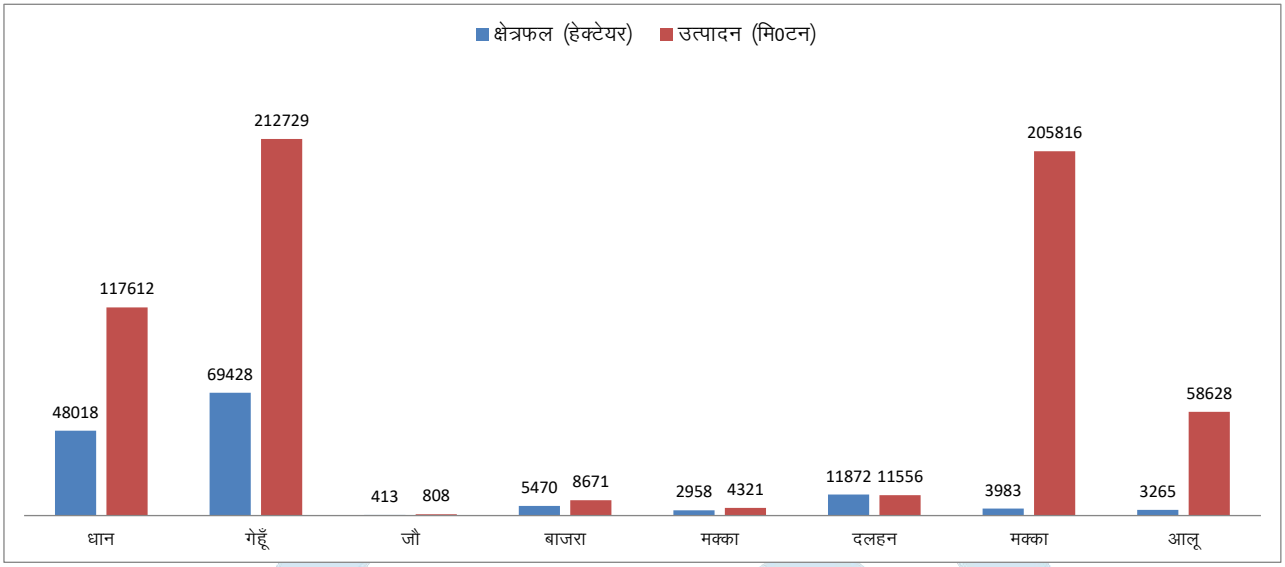
भूमि का उपयोग (हेक्टयर)

कुल क्षेत्रफल	152678
वन भूमि	46
भू–क्षेत्र जो खेती के लिए उपलब्ध नहीं है	27954
स्थाई चारागाह	24
विविध वनस्पति	2458
खेती योग्य बंजर भूमि	2274
वर्तमान परती भूमि	20316
अन्य परती	4471
शुद्ध बुआई क्षेत्र	95164
कुल या सकल फसल क्षेत्र	157817
भू–क्षेत्र जिसपर एक बार से अधिक खेती की	62653
फसल सधनता	1.66



वरूणा के प्रवाह क्षेत्र विकास खण्ड में फसल का क्षेत्र एवं उत्पादन –

फसल	क्षेत्रफल (हेक्टेयर)	उत्पादन (मि0टन)	औसत उपज (किग्रा. प्रति. हे.)
धान	48018	117612	22.49
गेहूँ	69428	212729	30.79
जौ	413	808	17.63
बाजरा	5470	8671	12.73
मक्का	2958	4321	18.82
दलहन	11872	11556	9.79
मक्का	3983	205816	516.74
आलू	3265	58628	170.86



प्राचीन कृषि कला मानव जीवन के आर्थिक विकास के मुख्य सोत्र है। वरूणा नदी अपने उद्गम स्थान से मैदानी भागों के भूमि निर्माण से फसल क्षेत्र के लिए पहचान रखती है। जिसमें खरीफ, रबी व जायद फसल के क्षेत्र समिति है। वरूणा नदी मानव के विविध क्रियाकलाप संस्कृतिक उत्सव, मेला, कृषि, मत्स्य, आर्थिक समृद्धि के लिए आवश्यक अवसर प्रदान करती है। जिससे दोनों तटों पर स्थिति गाँवों में पिण्डरा, बड़ागाँव, हरहुआ, सेवापुरी, आराजी लाइन, काशी विद्यापीठ विकास खण्ड में खरीफ, रवी व जायद मिश्रित कृषि की जाती है। जलीय कृषि (आर्द्र फसल) में सिंघाडा कवलगट्टा (तिन्नि का चावल) कुमुदनी के फल बीज का उत्पादन किया जाता है। जिसमें प्रमुख्यतः गाँव ईसरवार भिटकुटी, बलुआ हरेहु, कुड़ी, सत्तनपुर इंदरपुर नवेद, गद्दोपुर, रखी, तेन्दुई खण्डा धुरापुर, स्सूलपुर, सलिवाहनपरु, खलिया, जगापट्टी, परसीपुर, रमेश्वर, लच्छीपुर, चक्का, हीरमपुर, पाडेपुर, अवसानपुर, मतसार, खेवली, गाँवों में फसल का समन्वित रूप मिलता है। वरूणा नदी वर्षाकाल में अपने जल संचयन एवं पवाह मार्ग में पड़ने वाले सभी गाँवों के ताल, झील पोखरों के खेत, गाँव के अधिक जल को अपने साथ प्रवाह मार्ग लेकर चली आती है और अपने तटों के और प्रवाह क्षेत्र में मिट्टी को छोड़कर उपजाऊ मैदान का निर्माण करती है। वरूणा अपने प्रभाव मार्ग में उपजाऊ मिट्टी का निर्माण करती है। जो मिट्टी खरीफ की फसल के लिए आवश्यक होती है। जिसमें नाइट्रोजन, फासफोरस पोरस की मात्रा की अधिकता होती है।

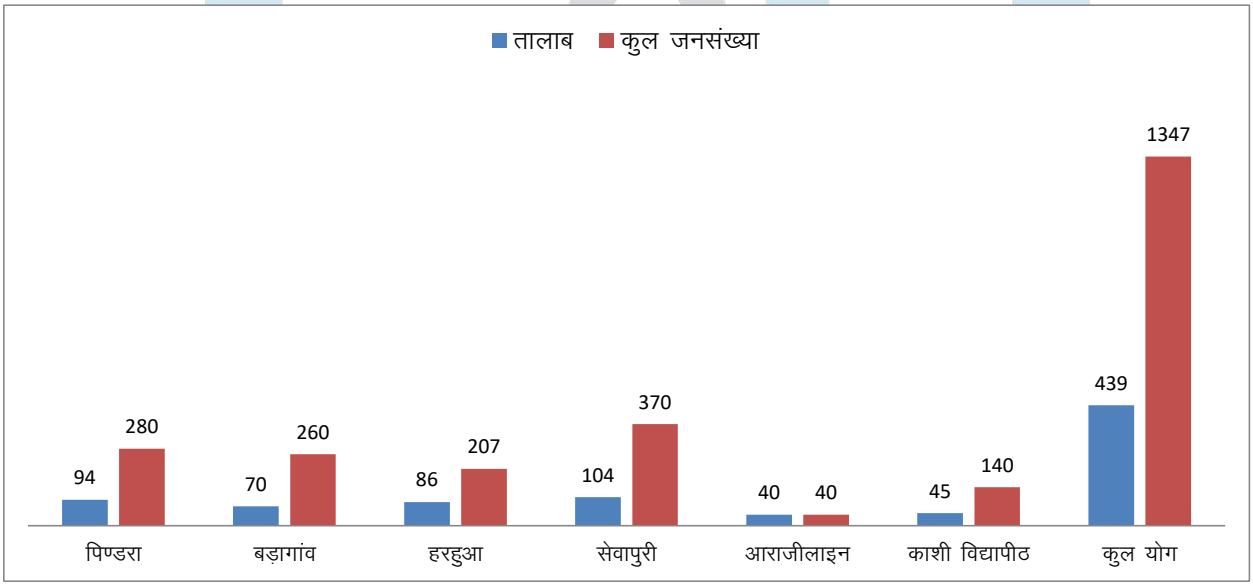
मत्स्य उत्पादन : वरूणा नदी के दोनों किनारे पर स्थित गाँव में जाति समुदाय का एकीकरण पाया जाता है। हमारे जाति व्यवस्था कार्य निपुणता के आधार व्यवसाय को निर्धारित करता है। उसी में हिन्दू समुदाय के जाति मल्लाह (केवट) है। जिसको नदी जल के साथ क्रीडा करने, अर्थात (तैराकी) नाव चलाने व जलीय जीवों की पहचान का जन्मजात एकाधिकार प्राप्त है। इन सभी लोगों के आजीविका का मुख्य साधन मत्स्य पालन, एवं मछली पकडने का है। भारतीय समाज में मछली का उपयोग शुभ कार्य के प्रभाव से माना जाता है। लगातार मछली के उपभोक्ता में वृद्धि के कारण मांग की पूर्ति नहीं हो पाती। वर्तमान उत्तर प्रदेश मछली के उपभोक्ता राज्यों में से एक है और उत्पादन कम के होने के कारण आन्ध्र प्रदेश

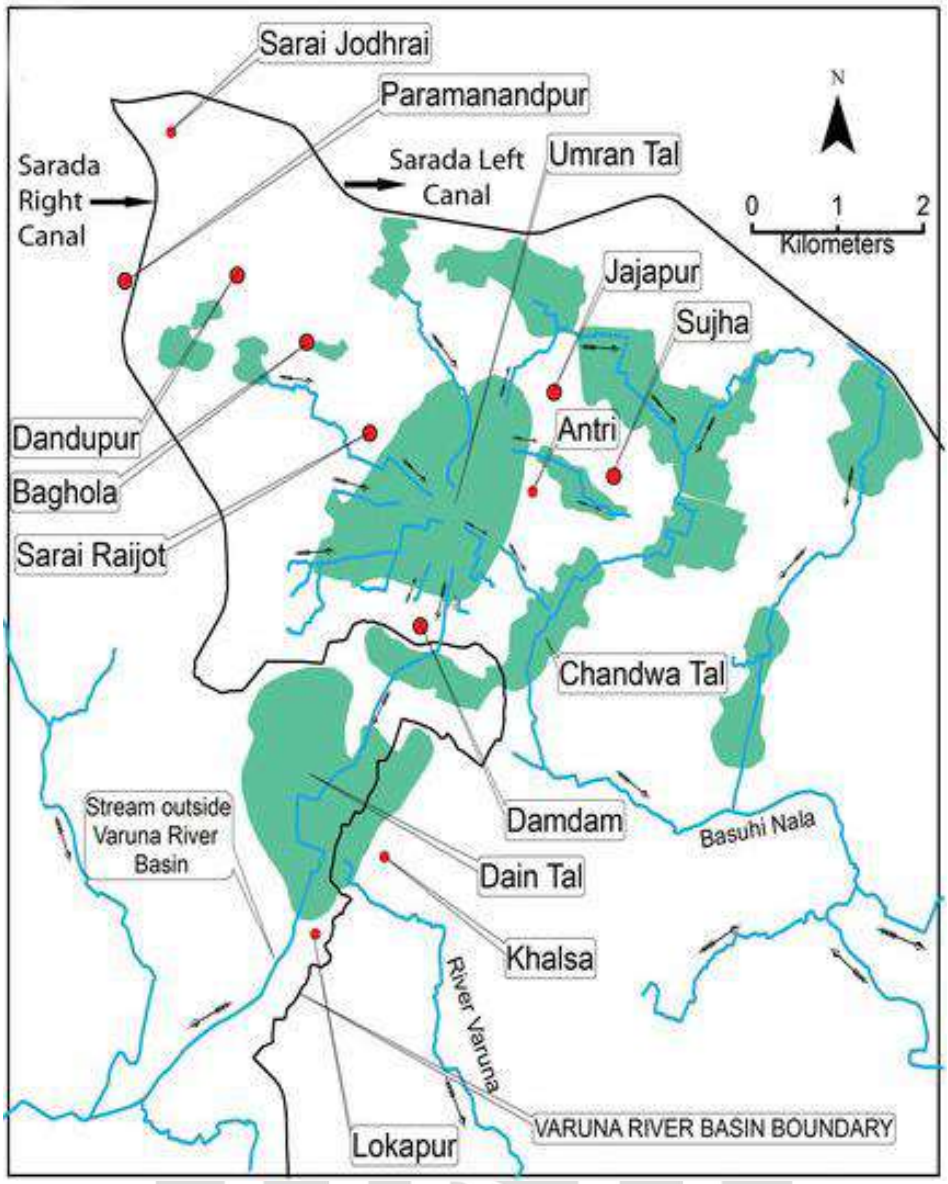
की मछली उत्पाद उद्योग का उ0प्र0 बाजार है वरूणा नदी स्थानीय लोगों के लिए मछली उत्पादन का मुख्य स्रोत है। नदी से मछली पकडने के लिए लोग छोटी–छोटी नाव एवं जाल का प्रयोग करते है।

वरूणा नदी क्षेत्र में मत्स्य उत्पादक तालाबों एव श्रमिको की संख्या

विकास खण्ड	तालाब	कुल जनसंख्या	पुरूष जनसंख्या	महिला जनसंख्या
पिण्डरा	94	280	218	40
बड़ागांव	70	260	225	35
हरहुआ	86	207	280	27
सेवापुरी	104	370	350	20
आराजीलाइन	40	40	75	15
काशी विद्यापीठ	45	140	170	30
कुल योग	439	1347	1240	167

स्रोत : ग्रामवासियों, पंचायत सदस्यों के द्वारा सर्वेक्षण एवं सांख्यिकी पत्रिका–2011





साथ ही उपरी भागों के जल के संचययन के कार्य प्रवृति में वर्षा काल के समय प्रायः सभी गाँवों में पानी संचयन के लिए वने प्राकृतिक संसाधन–ताल, बौली, पोखरी, पोखरा, सोतिया, वॉहा, नाला आदि में जल का संचययन करते है। जिसमें जल कृषि संसाधन में मछलीयाँ व जलीय फसलों का उत्पादन करते है। जो कार्य व्यक्तिगत या सार्वजनिक दो रूपों में पाये जाते है। सभी जलीय भाग में मछली पालन किया जाता है उ0प्र0 सरकार के द्वारा मत्स्य पालन के लिए योजना बनाकर लोगों को प्रोत्साहित किया जाता है और व्यक्तिगत भू–भाग के मछली उत्पादन के लिए तालाब बनाकर मत्स्य पालन के लिए सब्सिडी के माध्यम से बढ़ावा दिया जा रहा है। प्रायः सभी गाँवों के कृषकों द्वारा आय में वृद्धि के लिए मत्स्य पालन किया जा रहा है।

आर्थिक विकास में वरूणा नदी का महत्व :

वरूणा नदी के प्रवाह क्षेत्र में सामाजिक, आर्थिक क्रियाओं में वरूणा संस्कृति का प्रभाव है। लोगों के द्वारा अपने सांस्कृतिक उत्सव को नदी की आज्ञा व आर्शीवाद से प्रारम्भ करना और वरूणा नदी की पूजा अर्चना से मंगल कामना को प्राप्त करना महत्वपूर्ण हो जाता है। इसके तटीय क्षेत्रों के गाँवों के जल संचयन पशु–पक्षी के लिए पीने के पानी, सिंचाई के लिए जल को खेतो तक पहुँचाना। वरूणा नदी प्रवाह

मार्ग में पड़ने वाले सभी गाँवों को जल समायोजित करती है सभी विकास खण्ड पिण्डारा 190 गाँव, बड़ागाँव 138 गाँव, हरहुआ 186 सेवापुरी 204, आराजी लाइन 184, काशी विद्यापीठ 163 गाँवो अर्थात 1065 गाँव में जल संचयन के प्राकृतिक स्थान है। जो मत्स्य पालन एवं मत्स्य व्यवसाय–जलीय वनस्पति की कृषि कार्य के लिए उपलब्ध है। नदी द्वारा मिट्टी में परिवर्तन क्रिया होती है।

वरूणा नदी के द्वारा स्थानीय लोगों की आजीविका :

मत्स्य एवं कृषि (फसल व पशुपालन) के द्वारा 1065 गाँवों की अर्थव्यवस्था में आर्थिक वृद्धि होती है। लगभग 108745 हे0 क्षेत्रफल कृषि उत्पाद से कृषको की आय में वृद्धि होती है। वर्तमान में कृषक उन्नतिशील कृषि उत्पादन के लिए कार्यशील है। जो अधिक से अधिक लाभ के लिए व्यापारिक कृषि फसलों का उत्पादन करते है। जो उनके आर्थिक आय के मुख्य स्रोत है।

निष्कर्ष :

वरूणा नदी के क्षेत्र के 6 विकासखण्डों में गाँवो की कृषकों की संख्या में 111623 कृषक परिवार विविधतापूर्ण कृषि फसल का उत्पादन, सब्जी की फसल का उत्पादन कर बाजार में पहुँचाकर आय के स्रोत का सृजन करते है। जिसमें प्रत्यक्ष एवं अप्रत्यक्ष रूप से कुल श्रमिक पुरूष 85144 महिलाएं 26579 कृषि कार्य में लगे है जो सीमान्त एवं लघु कृषक है जिनकी आजीविका के साधन के रूप में केवल वरूणा नदी है।

वरूणा नदी उपजाऊ मिट्टी निर्माण में सहायक है। इस क्षेत्र में कृषि उत्पादन व कृषि आधारित उद्योग व कुटीर उद्योग कृषि की विशेषता है। वनस्पति, पशुपालन व पशु उत्पादन आधारित उद्योगों की प्रमुखता हैं, मत्स्य पालन एवं जलीय आर्द्र कृषि की विशेषताएं कृषकों व मजदूरों को अपनी तरफ आकर्षित किया है। वहीं वरूणा नदी अपने क्षेत्र में मिट्टी के निर्माण के साथ अपने क्षेत्र के आर्थिक विकास में मानव जीवन के लिए वरदान है।

सन्दर्भ ग्रथ

1. तिवारी आर.सी. – भारत का भूगोल, अपवाह, पेज 90–92।
2. सांख्यिकीय पत्रिका जनपद वाराणसी 2011
3. इण्टरनेंट
4. शोध पत्र – ISG वरूणा नदी वेसिन Vol अंक 10 अप्रैल 2016 पृष्ठ 48

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Influence of Different Plant Growth Regulators on yield and quality parameters of Radish (*Raphanus sativus* L.)

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Abstract : Present experiment was conducted during Rabi season 2024-25 at Horticulture field, Department of Horticulture, Udai Pratap Autonomous college, Varanasi to study the "Influence of Plant Growth Regulators on yield and quality parameters of Radish (Raphanus sativus L.). The experiment was laid out in Randomized Block Design with seven treatments and three replications. The treatments used i.e. three different concentration of GA3 and NAA at 10, 20 and 30 ppm and control. The results shows significant improvements in root length, root diameter and yield per hectare under higher concentrations of GA_3 and NAA. Maximum yield was recorded under GA_3 @ 30 ppm, followed by NAA @ 30 ppm. These results shows that plant growth regulators play a vital role in enhancing the productivity of radish.

Index Term : Plant growth regulators, growth, yield and quality

INTRODUCTION

Radish is an important root vegetable crop. It belongs to Brassicaceae family and has diploid chromosome number (2n = 18). This vegetable is grown for its fleshy roots and leaves in many tropical and sub-tropical regions of the world. It is native of Europe and Asia (*Thompson & Kelly 1957*). It is a fast growing, cool season crop grown for its enlarged tap root.It has a wide range of shapes, such as cylindrical, globular and tapering. The outer skin colour usually white. The Asiatic varieties, which are primarily grown in a tropical climate, produce edible roots in the first season and seeds in the second season as a biennial crop.The plant has rosette-shaped leaves covered with stiff bristles. It produces an edible, fleshy root with a fusiform shape, which develops from both the primary root and the hypocotyl. Radish has a wide range of variation in root size, shape and length. It is highly cross-pollinated due to the sporophytic system of self- incompatibility. The inflorescence is typically a raceme and arises on the main stem. The flowers are cruciform, symmetrical, and bisexual, with complete homogamy and they are rose or lilac in colour. The androecium of the flower consists of six stamens arranged in two whorls, while the gynoecium is formed by a bicarpellary, syncarpous ovary. The fruit of the radish is a true silique, typically 2.5 to 7.5 cm long, with a pithy interior, and it does not dehisce when ripe. The use of plant growth regulators such as GA_3 and NAA have shown potential to enhance vegetative growth, root development, yield and quality. GA_3 is known for cell elongation and shoot growth, whereas NAA influences root formation and nutrient uptake. The present investigation aims to assess the influence of foliar application of GA_3 and NAA at different concentrations on the yield and quality parameters of radish.

RESEARCH METHODOLOGY

The study was conducted during Rabi season in 2024-25 at the horticulture field, Department of Horticulture, Udai Pratap Autonomous college, Varanasi to study the "Influence of Plant Growth Regulators on growth and

Yield of Radish (*Raphanus sativus* L.). The experiment was laid out in Randomized Block Design with seven treatments and three replications on the variety Kashi Hans. The treatments used i.e. three different concentration of GA3 and NAA at 10, 20 and 30 ppm and control. The seeds were sown on 4 November. The treatments used i.e. three different concentrations of GA3 and NAA at 10, 20 and 30 ppm and control. The seeds were sown at 4 November.The observation were recorded on root length, root yield (q/ha), percent dry matter, Ascorbic acid (mg/100 g) and Total Soluble Solid (TSS).

Results and discussion

Yield Attributes

The study of mean value pertaining to vegetative characters shows that various treatments of growth regulators significantly affected the plant height, number of leaves per plant , length of leaves. GA3 was most effective followed by NAA. All the growth regulators treatment except GA3 at 30 ppm, has shown significant effect in improving the plant height, leaf length and leaf width of plant as compare to control.

The maximum value of root length was observed under treatment T4 was (34.16 cm), diameter of root (4.40 cm), average root weight , yield per plot , yield per hectare (426.25 q/ha) was recorded (GA3 at 30 ppm). The minimum value of yield and yield attributes such as root length (28.12), diameter of root , average root weight and yield per hectare were recorded under control. These findings, are also consistent with observations recorded by Agnihotri, *et al.* (2021), Jatav (2007), karuppaiah *et al.* (2007), Reddy, *et.al.*, (2021), Jatav, (2007) and Mukherjee and Roy (2006).). Gibberellic acid may have increased nutrient uptake by increasing cell division and elongation, resulting in increased root length (Shruthi *et al.*, 2016), Jat (2018). The fresh weight of root was greatest at the highest concentration of GA3, which Hopkins attributes to three factors : dry matter, cell division and expansion, all of which result in increased fresh weight of root. This increase in yield as well as yield attributes by gibberellic acid may be due to increased vegetative growth and foliage giving better opportunities for photosynthetic activity resulting in high yield reported by Ashraf, *et al.*, (2018) and Mishra and Pathak (2005). The enhancement in growth parameters was primarily due to the hormonal impact of plant growth regulators, which stimulated both cell division and elongation.

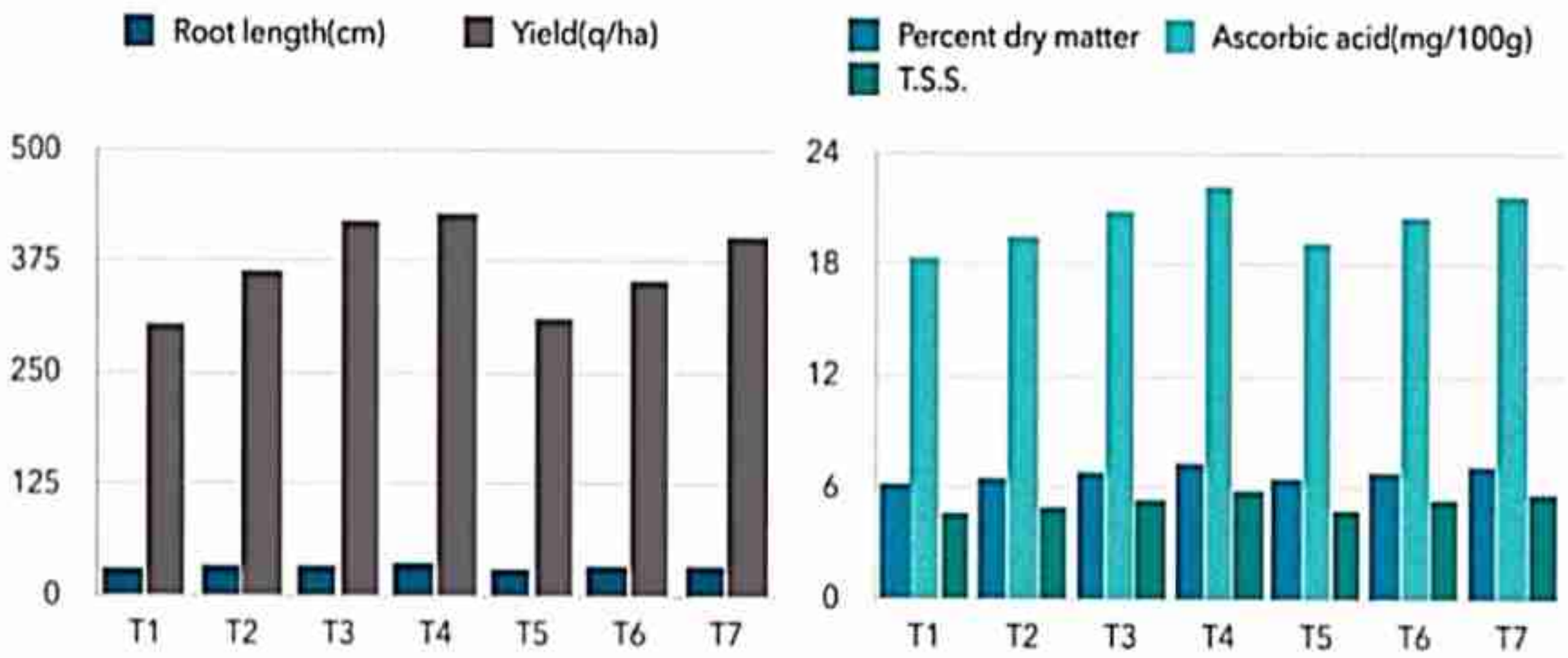
Quality Attributes

The results of this study has clearly shown that GA3 and NAA had shown significant increase on quality attributes such as percent dry matter and Ascorbic acid when compared to control. The maximum values of quality parameters i.e. percent dry matter (7.24%), Ascorbic acid content (22.1 mg/ 100 g) and TSS (5.70 °Brix) was recorded in T_4. On the other hand, minimum percent dry matter (6.10%), ascorbic acid content (18.2 mg/100 g) and TSS (4.50 °Brix) were recorded under control. These results were in close argument with the observation recorded by Chauhan and Tandel (2010) in cabbage, Ganapathi, (2006). in carrot, Vishwakarma, *et.al.*, (2017) in sprouting broccoli. The increase in ascorbic acid content in radish could be attributed to improved availability of energy and assimilates supporting vigorous vegetative growth, as observed by Mishra and Singh (1986) in cauliflower and by Agnihotri, *et al.*, (2021) in radish.Additionally, GA_3 influenced genetic processes such as protein synthesis, nutrient translocation, and transpiration, leading to the improvement of quantity and quality parameters.Similar, result were founded by Abdel, *et al.*, (2010), Thompson & Kelley. (1957)), karuppaiah *et al.* (2007), Shweta *et al.* (2018), Shruthi *et al.* (2016), and Bagri, M. B. (2021) all made similar observation.

Table : Effect of different growth regulators on Yield and Quality of radish

Treatment	Root length(cm)	Yield (q/ha)	Percent dry matter	Ascorbic acid (mg/100g)	T.S.S. Content (°Brix)
T_1	28.12	302.06	6.10	18.2	4.5
T_2	30.62	362.83	6.45	19.5	4.9
T_3	32.30	419.22	6.80	20.8	5.3
T_4	34.16	426.25	7.24	22.1	5.7
T_5	29.8	310.76	6.50	19.1	4.8
T_6	30.63	352.66	6.70	20.4	5.2
T_7	31.91	401.22	7.05	21.7	5.6
SEm±	0.38	4.92	0.12	0.31	0.09
CD at 5%	1.16	15.15	0.37	0.95	0.27

Figure : Effect of different growth regulators on Yield and Quality of radish



Conclusion

The present study shows that the application of plant growth regulators (GA_3 and NAA) has significantly improved the yield and quality attributes of radish. Among the treatments GA_3 at 30 ppm has shown best result in root length, marketable root yield (q/ha), percent dry matter, Ascorbic acid, T.S.S. Hence, GA3 at 30 ppm can be used to increase yield and quality characters of radish

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Reference:

Abdel, C. G., & Al-Sabari, M. R. S. (2010). Production of well irrigated radishes (*Raphanus sativus* L.): 3-The influence of naphthalene-3-acetic acid (NAA) on growth and yield of furrow cultivated Local black radish cultivar. *Babylon Education Journal*, *1*(5), 98-106.

Ashraf, M. I., Sajad, S., & Iqbal, R. (2018). *Effect of Plant Growth Regulators (IBA and 2,4-D) on the Morphology and Biochemical Characteristics of Radish (Raphanus sativus L.).* 5(2). https://doi.or/10.21767/2394-9988.100071

Agnihotri, K. M., Dev, P., Kumar, J., Choudhary, K., Kumar, V., & Kumar, A. (2021). Effect of different organic manures on growth and yield parameters of radish (*Raphanus Sativus* L.) cv. Japanese white. *Progressive Agriculture*, *21*(1), 17-22.

Bagri, M. B. (2021). Effect of spacing and gibberellic acid (GA_3) on growth, yield and quality attributes of radish (*Raphanus sativus*) (M.Sc. Thesis). Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur.

Chauhan, U. M., & Tandel, Y. N. (2010). Effect of plant growth regulators on growth, yield and quality of cabbage (*Brassica oleracea var. Capitata* L.) cv. Golden Acre. Asian Journal of Horticulture, 4(2), 512–514.

Dayal, A., Kishore, M. S., Rai, P. K., & Thomas, N. (2022). Influence of bioinoculants and plant growth regulators on growth yield and yield attributes of Radish (*Raphanus sativus*) variety- sweta. *Indian Journal of Extension Education*, *58*(2), 50-55.

Reddy, J. N. P. K., Dayal, A., Rai, P. K., & Thomas, N. (2021). Study of the effect of various organics, chemicals, and growth regulators treatments on growth, yield, and yield attributing traits in radish (*Raphanus sativus* L.). International Journal of Environment and Climate Change, 11(10), 91–96.

Ganapathi, M. (2006). Influence of organics, micronutrients and plant growth regulators on productivity potential in carrot (*D. carota* L.) (Doctoral dissertation, University of Agricultural)

Gopal, A., Jangre, N., Sahu, M. K., Pandey, S., & Deepshikha. (2023). Studies on effect of different plant growth regulators on growth and yield of radish (*Raphanus sativus* L.) in Chhattisgarh plains. The Pharma Innovation Journal, 12.Horticulture Statistics Division. Department of Agriculture & Farmers welfare, 2020-21.

Jatav, B. S. (2007). Effect of different plant growth regulators on growth and yield of radish (*Raphanus sativus* L.). M.Sc. (Ag) Thesis, College of Agriculture, Gwalior, JNKVV.

Jat, S. (2018). *Response of gibberellic acid and nitrogen on growth, development and yield of radish* (Doctoral dissertation, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur).

Karuppaiah, P., Kumar, S. R., & Sendhilnathan, R. (2007). Effect of growth regulators on growth, physiological and yield attributes of radish. Advances in Plant Science, 20(2), 457–459.

Mishra SK and Pathak SC. (2005). The effect of growth regulators on growth and yield attributes of Radish var. Japanese White. *Survey of Horticulture Journal* 41 (3). (118-120)

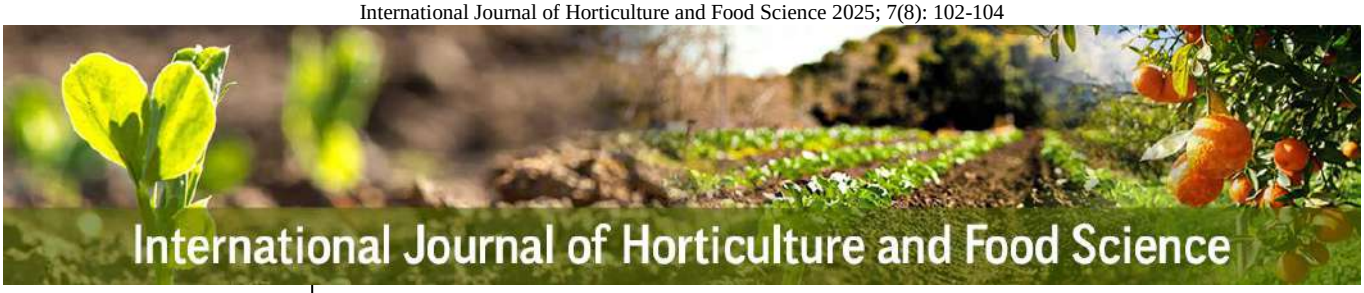
Mukherjee DK and Roy MC. (2006). Effect of seed treatment with gibberellic acid on germination, growth and yield of Radish (*Raphanus sativus* L.). Advances in Horticulture Science BCKVV. 181(2): 115-117.

Shruthi, H. T., Srinivasa, V., & Ibaad, M. H. (2016). Influence of spacing and growth regulators on growth, flowering, seed yield and quality of radish (*Raphanus sativus* L.) Cv. Pusa Chetki. *Research In Environment and Life Sciences, 9*(3), 288-291.

Shweta, D. M., Thakur, V., & Datta, S. (2018). Effect of different plant growth regulators (GA3 and NAA) on growth and yield parameters of radish (*Raphanus sativus* L.) Var. Pusa Reshmi. *Journal of Pharmacognosy and Phytochemistry, 7*(3), 3434-3437.

Thompson, C. H., & Kelley, C. W. (1957). Vegetable crops. New York, NY: McGraw-Hill Book Company, Inc.Tomar, A., et al. (2021). Study of plant growth regulators on growth parameters of radish (Raphanus sativus L.). International Journal of Engineering Science Invention (IJESI), 10(10), 58–60. https://doi.org/10.35629/6734

Vishwakarma, S., Bala, S., Kumar, P., Prakash, N., Kumar, V., Singh, S. S., & Singh, S. K. (2017). Effect of Nitrogen, Naphthalene acetic acid and Gibberellic acid on growth, yield and quality of broccoli (*Brassica oleracea var. italica* L.) Cv. Sante. *Journal of Pharmacognosy and Phytochemistry, 1*, 188-194.



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The effect of micronutrients and GA_3 on growth and yield of tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan

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Abstract
This study was conducted with the objective to determine the effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan and an experiment was conducted at the horticultural farm, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized block design (RBD) with seven treatments replicated three times comprising GA_3 and micronutrients with control i.e. T_1: GA_3 (50ppm), T_2: GA_3 (100ppm), T_3: $ZnSO_4$ (0.5%), T_4: $ZnSO_4$ (1%), T_5: Boric acid (50ppm), T_6: Boric acid (100ppm) and T_7: Control. Significantly, differences were found for plant growth parameters *viz*. plant height (cm), number of branches plant^{-1}, number of flower cluster^{-1}, number of cluster plant^{-1}, was recorded highest in T_2: GA_3 (100ppm). The treatment T_2: GA_3 (100ppm) was also found best in early days to 50% flowering, days to first fruit set and yield attributes *viz*., no. of fruit per cluster, no. of fruit plant^{-1}, average fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg) and fruit yield (q/ha) in tomato cv. Kashi Chayan. It is revealed that the use of GA_3 at the concentration of 100ppm, considerably increased the vegetative growth parameters and significantly increased growth and yield of tomato.

Keywords: Micronutrients, GA_3, Growth and Yield

Introduction
Tomato (*Lycopersicon esculentum* Mill.) is a member of the Solanaceae family and is a diploid species with a chromosome number of 2n=24. Originally native to Peru and Mexico, it is now widely cultivated across the globe due to its ability to thrive in a variety of soil types and climates (Gerszberg *et al.*, 2015) [4]. The top tomato-producing countries include China, the United States, India, Egypt, Turkey, Iran, Mexico, Brazil, and Indonesia [FAO, 2022]. Tomato is a warm-season crop that is sensitive to cold temperatures (Afshari *et al*., 2014) [1]. It can be cultivated in both the wet and dry seasons, provided the annual rainfall ranges from 60 to 150 cm. However, excessive rainfall during its growth period can be detrimental to the plant. Micronutrients play a crucial role in plant processes, and foliar application of these nutrients can enhance both the quality and yield of tomatoes (Ali *et al*., 2012) [2] by boosting the photosynthetic activity in green plants (Singh and Tiwari, 2013) [13]. Micronutrients management is essential to boost the crop production and also increased the fruits quality. Boron and zinc important micronutrient for quality tomato fruit production. Zinc regulates growth and also promotes balanced sugar consumption and Boron helps to providing some nutrients and essential for proper development of their fruits and seeds. Gibberellic acid is a key growth regulator with various potential applications for altering plant growth, yield, and yield-related traits (Rafeekher). Considering the facts, the current study aims to examine the effects of Micronutrients and GA_3 on the growth and yield of tomato.

Materials and Methods
A field experiment entitled " The effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan" was conducted at the experimental field of Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized

block design (RBD) with seven treatments replicated three times comprising GA_3 and micronutrients with control i.e. T_1: GA_3 (50ppm), T_2: GA_3 (100ppm), T_3: $ZnSO_4$ (0.5%), T_4: $ZnSO_4$ (1%), T_5: Boric acid (50ppm), T_6: Boric acid (100ppm) and T_7: Control. The collected data includes plant height (cm), number of branches plant^{-1}, number of flower cluster^{-1}, number of cluster plant^{-1}, early days to 50% flowering, days to first fruit set and yield attributes *viz*., no. of fruit per cluster, no. of fruit plant^{-1}, average fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg) and fruit yield (q/ha) in tomato cv. Kashi Chayan. The data was analyzed using analysis of variance (ANOVA), and mean separation was performed at a 5% probability level.

Results and Discussion

The data on the effects of various micronutrients and GA_3 on plant height at different growth stages were statistically analyzed and are detailed in Table 1. It clearly showed that the plant height differed significantly with each other, the maximum plant height (118.23 cm) was recorded in the treatment T_2 (GA_3 @ 100 ppm. The minimum plant height was noted 92.40 cm at the time of harvesting in treatment T_7 (Control). The data on the effects of various micronutrients and GA_3 on no. of branches per plant at different growth stages were statistically analyzed and are detailed in Table 1. It clearly showed that the no. of branches differed significantly with each other, the highest no. of branches (11.95) was recorded in the treatment T_2 (GA_3 @ 100 ppm). The lowest no. of branches was noted 7.10 at the time of harvesting in treatment T_7 (Control).

The shortest duration to reach 50% flowering in tomato plants was observed in treatment T_2 (GA_3 @ 100 ppm), requiring just 62.34 days. This was followed by treatment T_1 (GA_3 @ 50 ppm), which required 64.29 days. In contrast, the longest duration of 76.51 days to reach 50% flowering was recorded in the control treatment T_7. Onofeghara (1981) [8] reported similar findings, attributing them to the role of GA_3 in regulating flower initiation and development. GA_3 is crucial for both male and female fertility (Griffiths *et al.*, 2006) [5]. The data on the effects of various micronutrients and GA_3 on no. of flower per cluster were statistically analyzed and are detailed in Table 1. The highest number of flowers per cluster, averaging 6.86, was observed in treatment T_2 (GA_3 @ 100 ppm). This was followed by T_1 (GA_3 @ 50 ppm) and T_6 (Boric acid @ 100 ppm), which had 6.47 and 5.38 flowers per cluster, respectively. The highest number of clusters per plant, at 5.86, was observed in treatment T_2 (GA_3 @ 100 ppm), followed by T_1 (GA_3 @ 50 ppm). Both micronutrients and GA_3 had a notable impact on the days to the first fruit set during the 2023-24 period. The shortest duration to the first fruit set, at 72.77 days, was observed in treatment T_2 (GA_3 @100 ppm), followed by T_1 (GA_3 @ 50 ppm). Both micronutrients and GA_3 had a considerable impact on the timing of the first fruit picking during the 2023-24 period. The shortest time to the first fruit picking, at 87.20 days, was recorded in treatment T_2 (GA_3 @100 ppm), followed by T_1 (GA_3 @50 ppm) at 88.35 days.

The data on the effects of various micronutrients and GA_3 on no. of fruits per plant were statistically analyzed and are detailed in Table 2. Among the treatments, T_2 (GA_3 @ 100 ppm) yielded the highest number of fruits per plant at 47.80, showing a significant improvement compared to other treatments. This was followed by T_1 (GA_3 @ 50 ppm), which produced 44.60 fruits per plant. In contrast, the control (T_7) recorded a significantly lower number of fruits per plant (22.43).

The longest fruit length, measuring 6.10 cm, was observed in treatment T_2 (GA_3 @ 100ppm), which was significantly superior to other treatments. This was followed by T_1 (GA_3 @ 50 ppm) and T_4 ($ZnSO_4$ @ 1%), with fruit lengths of 5.98 cm and 5.05 cm, respectively. The shortest fruit length, at 3.57 cm, was recorded in the control group T_7. The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. The greatest fruit width, measuring 5.14 cm, was observed in treatment T_2 (GA_3 at 100 ppm), followed by T_1 (GA_3 at 50 ppm) at 4.98 cm. The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. The weight of individual tomato fruits varied significantly with the application of different levels of GA_3 and micronutrient. The highest average fruit weight (104.46g), was recorded in treatment T_2 (GA_3 @ 100 ppm), followed by T_1 (101.73g) and T_4 (98.40g). The lowest average fruit weight, 82.32g, was observed in the control (T_7). These findings are reported by Lilov and Donchev (1984) [7] Naeem *et al.* (2001) [9].

The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. Statistical analysis of the data on tomato fruit yield per plant (Kg) revealed significant differences. Different levels of GA_3 had a significant impact on the yield of fruit per plant. The highest yield, at 3.33 kg per plant, was achieved with 100 ppm GA_3, while the lowest yield, 1.56 kg per plant, was observed under control conditions.The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. Statistical analysis of the data on tomato fruit yield per hectare (q) revealed significant differences. The application of different levels of GA_3 significantly affected the fruit yield per hectare. The highest yield, 437.35 q/ha, was obtained with T_2 (GA_3 @ 100 ppm), followed by T_1 (GA_3 @ 50 ppm) at 407.87 q/ha whereas the lowest yield, 240.56 q/ha, was recorded in the control (T_7).

Conclusion

The results of the present study indicate that the application of GA_3 (50 ppm and 100 ppm) and micronutrients such as $ZnSO_4$ (0.5% and 1%) and boric acid (50 ppm and 100 ppm) notably enhanced vegetative growth, flowering, and significantly boosted tomato yield. Based on these findings, it can be concluded that GA_3 at a concentration of 100 ppm was the most effective treatment for improving both vegetative growth and yield in tomato variety Kashi Chayan.

Table 1: Effect of micronutrients and GA_3 on plant height, no. of branches, days to 50% flowering, no. of flower per cluster, no. of cluster per plant, days to first fruit set and days to first fruit picking

Tr. No.	Treatment details	Plant height (cm)	No. of branches	Days to 50% flowering	No. of flower per cluster	No. of cluster per plant	Days to first fruit set	Days to first fruit picking
T_1	GA_3 (50ppm)	115.75	11.03	64.29	6.47	4.37	73.51	88.35
T_2	GA_3 (100ppm)	118.23	11.95	62.34	6.86	5.86	72.77	87.20
T_3	$ZnSO_4$ (0.5%)	107.47	10.25	72.31	5.12	3.98	77.15	91.92
T_4	$ZnSO_4$ (1%)	109.32	10.98	71.03	5.26	4.32	76.87	89.99
T_5	Boric Acid (50ppm)	110.87	9.33	68.01	5.28	4.28	77.67	92.85
T_6	Boric Acid (100ppm)	112.17	9.98	67.20	5.38	4.08	76.37	90.98
T_7	Control	92.40	7.10	76.51	4.24	3.24	80.11	94.01
SEm±		1.95	0.13	1.44	0.05	0.04	1.45	1.36
CD at 5%		6.02	0.41	4.44	0.17	0.13	4.47	4.19

Table 2: Effect of Micronutrients and GA_3 on no. of fruits per plants, fruit length (cm), fruit width (cm), fruit weight (g), fruit yield (kg/plant) and fruit yield (q/ha)

Tr. No.	Treatment details	No. of fruits per plant	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Fruit yield (Kg/plant)	Fruit yield (q/ha)
T_1	GA_3 (50ppm)	44.60	5.98	4.98	101.73	3.27	407.87
T_2	GA_3 (100ppm)	47.80	6.10	5.14	104.46	3.33	437.35
T_3	$ZnSO_4$ (0.5%)	37.47	4.93	4.18	97.07	2.89	304.76
T_4	$ZnSO_4$ (1%)	39.38	5.05	4.25	98.40	2.93	321.02
T_5	Boric Acid (50ppm)	34.06	4.79	4.04	91.29	2.31	337.10
T_6	Boric Acid (100ppm)	35.99	4.86	4.13	95.30	2.64	353.20
T_7	Control	22.43	3.57	3.57	82.32	1.56	240.56
SEm±		0.71	0.07	0.07	1.01	0.03	6.43
CD at 5%		2.18	0.22	0.20	3.11	0.09	19.81

References

1. Afshari M, Afsharmanesh GHR, Yousef K. The effect of enriched organic fertilizer and methanol spray on the greenhouse-tomato yield. J Agric Sci. 2014;6(11):14-20.
2. Ali S, Javed HU, Rehman RN, Sabir IA, Naeem MS, Siddiqui MZ, Saeed DA, Nawaz MA. Foliar application of some macro and micronutrients improves tomato growth, flowering and yield. Int J Biosci. 2012;3(10):280-7.
3. Food and Agriculture Organization of the United Nations. World food and agriculture - statistical year book 2022. Rome: FAO; 2022: https://openknowledge.fao.org
4. Gerszberg A, Konka KH, Kowalczyk T, Kononowicz AK. Tomato (*Solanum lycopersicum* L.) in the service of biotechnology. J Plant Biotechnol. 2015;120:881-902.
5. Griffiths J, Murase K, Rieu I, Zentella R, Zhang ZL, Powers SJ. Genetic characterization and functional analysis of the GID1 gibberellin receptors in *Arabidopsis*. Plant Cell. 2006;18(3):399-414.
6. Kumar A, Biswas TK, Singh N, Lal EP. Effect of gibberellic acid on growth, quality and yield of tomato (*Lycopersicon esculentum* Mill.). J Agric Vet Sci. 2014;7(4):28-30.
7. Lilov D, Donchev T. Effect of Bulgarian gibberellin preparation on tomato fruiting. Gradinarska Lozarska Nauka. 1984;21(1):49-55.
8. Onofeghara FA. The effects of growth substance on flowering and fruiting of tomato (*Lycopersicon esculentum* Mill.). Phyton (Argentina). 1981;40(1):107-16.
9. Naeem N, Ishitiaq M, Khan P, Mohammad N, Khan J, Jamiher B. Effect of GA3 on growth and yield of tomato cv. Roma. J Biol Sci. 2001;1:448-50.
10. Rafeekar M, Nair SA, Sorte PN, Hatwal GP, Chandan PM. Effect of growth regulator on growth and yield of summer cucumber. J Soils Crops. 2002;12(2):108-10.
11. Ranjeet RB, Ram P, Meena ML. Growth, flowering, fruiting, yield and quality of tomato (*Lycopersicon esculentum* Mill.) as influenced by plant bio-regulators. Int J Plant Sci. 2014;9(1):67-71.
12. Singh HM, Tiwari JK. Impact of micronutrient spray on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.). HortFlora Res Spectrum. 2013;2(1):87-9.

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Chemical Regulation of Plant Secondary Metabolism Through Precision Agriculture and Targeted Bioactive Interventions

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ABSTRACT

The conventional agriculture is facing a two-fold crisis, it has to produce much more food and at the same time decrease dramatically the environmental impact, yet the homogeneous, input-intensive strategy does not fit the task. This review suggests a revolutionary synergistic combination of three fields in order to attain sustainable intensification. Precision Agriculture (PA) offers the data-driven nervous system to map both spatial and temporal variability of crops and soils. Developed Horticulture provides the physiological knowledge base to understand this data and use it in crop-specific management. Plant Bioactive Science proposes specific "bio-stimulatory instruments" like elicitors and biostimulants to direct plant metabolism. They then allow them to create a closed-loop approach in which spectral sensing forecasts phytochemical compositions, precision horticulture uses controlled stress to generate valuable secondary metabolites, and variable-rate technologies provide inputs with surgical precision. This paradigm changes the priority in favor of bulk yield and optimization of output and nutritional quality, taking an active role in the trade-off between biomass/biochemical product production. The barriers in terms of cost, data integration and complexities in biology still exist but the potential of sensor technology, artificial intelligence and nano delivery systems to operationalize this vision are expected going forward. This integration ultimately opens the door to phyto-chemically-optimized production systems that can achieve the highest nutritional value/unit of resource optimization which would enable agricultural innovation to meet the global food security and sustainability needs.

Keywords: Bioactive Compounds, Secondary Metabolism, Precision Horticulture, Sustainable Agriculture, Nutraceuticals

INTRODUCTION

It is the twin imperatives of global food security and sustainable intensification that creates the essential context of which the contemporary agricultural innovation should be assessed.[1] The world population that is estimated to go up to almost 10 billion by 2050 requires a significant growth in food production the estimates point to an increase of 60-70 percent of the current level in 2005. This pressure is intensely compounded by the destabilizing impacts of climatic change, which come in terms of higher occurrence of droughts, floods, heat stress and pattern changes in pestilence, which directly endanger crop stability and arable land. At the same time, there is also the paradox of agriculture upon itself: it needs to dramatically decrease its impact on the environment but increase the production. Traditional agriculture is a major source of greenhouse gas emissions, excessive utilization of freshwater, decline in biodiversity and extensive soil and water pollution by synthetic inputs.[2,3] This has created the main paradigm of sustainable intensification (SI), which is the generation of more output, with the same unit of land, water, and input and reducing environmental damage and improving the concept of ecosystem services. SI is not a technology but an objective conceptualization which requires a radical reorientation of homogeneous, input-intensive agriculture to knowledge intensive, accurate and ecologically combined management.[4,5] It is in this desperate context that the combination of three separate, but complementary fields precision Agriculture (PA), advanced Horticulture, and plant bioactive science, appears not only as a possibility, but as a systemic shift that requires evolution of our food production systems to become resilient, efficient and of high quality. Nevertheless, the prevailing paradigm of traditional agricultural activity is profoundly inadequately prepared to address the complicated needs of SI and has severe constraints on the ability to optimize yield as well as quality in a sustainable way. These restrictions are structural, based on a philosophy of standardization and application of bulk input. To begin with, the traditional management considers fields as homogenous units, which results in the indiscriminate use of water, fertilizers and pesticides. This method disregards the natural spatial differences in soil texture, nutrient levels, organic material, topography and micro climate. The effects are two fold: hefty input wastes in surplus areas that do not need them, and increased costs and pollution and sub-optimization applications in areas where they are actually needed generating yield discrepancies in the same field.[6,7] This was an inefficient use of resources that is economically and environmentally unsustainable resulting in nutrient runoffs which result in eutrophication and groundwater contamination; over-irrigation intensifies water scarcity and salinization. Second, the standard practices tend to destroy the very resource base that they rely on. Repeated ploughing enhances water-sustaining and water-filtering properties, compromising the earth structure, biodiversity and organicness of the soil-based microbes- the source of sustainable fertility. The excessive use of the chemical pesticides leads to disruption of the natural pest-predator relationships, development of resistant pest and weed biotypes, and damages non-target organisms, including pollinators which are vital to a variety of horticultural crops.[8,9]

In respect of yield, the traditional systems have arguably reached a physiological plateau of key staple crops in the prevailing management paradigm, and there is less and less input payoff. The optimization of yield is normally accomplished by utilizing genetic potential and chemical inputs, without paying much attention to the internal physiological conditions of the plant and its dynamical relation to the microenvironment. As an example, the use of nitrogen fertilizer on an interval basis as opposed to the nitrogen status and assimilatory capacity of the plant in real-time may cause luxury consumption, overgrowth of vegetation at the cost of reproductive yield and slow maturation.[10,11,12] Moreover, traditional systems are ill fitted in controlling abiotic stress on-the-fly. An impending drought or heatwave is usually dealt with on the run, and maybe not at all, with irrigation, instead of being dealt with on the proactive by physiological priming of plants to increase their intrinsic tolerance mechanisms, and result in avoidable losses in yield. The key weakness of traditional practice, especially with high-value horticultural crops, perhaps, is that it often ignores quality as a complex characteristic. The emphasis on the tonnage per hectare does not take into account the key parameters that are crucial to nutritional value, resultant shelf life, and consumer preference: concentration of health-promoting bioactive compounds (e.g., polyphenols, carotenoids, vitamins), flavor profile, texture

and uniformity. These quality attributes are very sensitive to the management.[13,14] Irregular supply of water or nutrients, such as that of blossom-end rot in tomatoes or bitter pit in apples, are also the cause of a disorder. More implicitly, value-added bioactive compounds are commonly products of secondary metabolism in a plant, which is commonly enhanced in the presence of gentle, controlled stresses (eustress) a notion abhorred by the aim of conventional farming to eradicate all stress. High-input, uniform environments can maximize size and speed and yield diluted produce that is of lower nutrient density and has reduced resilience. Direct extensions of quality failures in the field are known as post-harvest losses, which have been estimated to range between 30-40% of the fruits and vegetables produced in the world, with the lower phytochemical composition of the produce or the physical integrity decomposition being more rapid.[15,16]

Fundamentally, traditional agriculture has a simplistic input output framework that is becoming increasingly inconsistent with the upheaval of plant biology, soil ecology and climate volatility.[17,18] It is offloading environmental expenses, wasting resources, homogenizing management in lieu of in-field potential, not strategically bringing the full potential of plant physiology to bear on robust yield and high quality. This challenging status quo forms an interesting problem statement: An urgent requirement is the transformative and knowledge-based framework capable of dynamically monitoring and reacting to spatial and temporal variability (PA), implementing the deep physiological knowledge to control plant performance and secondary metabolism (Horticulture), and using specific, biologically-grounded compounds to evoke the desired plant responses (Bioactives). These three pillars, combining, offer the synergistic remedy and blanket prescriptions will be substituted by the dynamic and plant-oriented dialogue thus filling the major gaps that are quite often left by traditional methods to get to the actual objectives of sustainable intensification.[19,20]

Precision Agriculture: Core Principles and Technologies

Fundamentally, Precision Agriculture is more of a paradigm shift of the traditional unified, whole-field approach to site specific, data-driven approach. It is based on the fact that it acknowledges and controls in-field spatial and temporal variability in order to achieve maximum economic returns, resource efficiency, and environmental stewardship. This is operationalized by a cycle of observation, diagnosis and action made possible by a package of interdependent technologies.[21,22] Remote Sensing is the major observational layer as it can give multi-scale information on crop status. Satellite systems (e.g. Sentinel-2, landsat) can provide synoptic, periodic images which are suitable to track seasonal patterns and regional planning. Unmanned Aerial Vehicles (UAVs or drones) support an increased spatial and temporal resolution, that is capable of yielding detailed spectral information (including both multispectral and thermal imaging) of the landscape to identify the early cues of water stress, nutrient deficiency, or disease hotspots, before they are visible to the human eye.[23]

Table 1: Core Limitations of Conventional Agriculture vs. Solutions from the Integrated PA-Horticulture-Bioactives Framework

Aspect	Limitation of Conventional Agriculture	Solution from Integrated Framework
Spatial Management	Treats field as homogeneous; blanket application of inputs	PA manages in-field variability via sensors & VRT; applies inputs site-specifically.
Resource Efficiency	High waste, pollution, and cost due to over-application.	Precise application reduces waste, lowers environmental footprint, and optimizes ROI.
Yield Optimization	Approaches physiological plateau; reactive stress management.	Proactive priming with bioactives; real-time stress mitigation via PA sensors & models.
Quality Focus	Neglected or diluted; emphasis on tonnage over nutritional density.	Active elicitation of secondary metabolites via precision horticulture & bioactives.
Soil & Ecosystem Health	Degradation through tillage, erosion, and chemical overuse.	Reduced chemical load; potential for enhanced soil biology via targeted biostimulants.
Decision Basis	Schedule-based, reactive, and empirical.	Data-driven, predictive, and based on real-time plant physiology.

The finest quality data (e.g. the electrical conductivity of soil, pH, and real-time canopy structure) is supplied by proximal sensing, which incorporates ground sensors on tractors or a

stationary installation (e.g. NDVI via Greenseeker).[24,25] The multi-level sensing strategy generates the multi-layered data stream of biophysical parameters of crops. Nevertheless, raw data cannot be sufficient; it needs a framework to be interpreted and make spatial decisions. It is at this stage that Geographic Information Systems (GIS) and Spatial Data Analysis is essential. GIS can be considered as the digital brain of PA, which combines the dissimilar layers of data such as soil maps, yield histories, remote sensing indices, topography and makes them a single unified database that is georeferenced. Kriging and clustering algorithms are then used as spatial statistical methods to determine coherent management zones in an area.

These spaces identify regions of similarity and potential in place of the concept of a homogenous field to a mosaic of individual micro-managements units. The practical deliverable of this analysis is a prescription map. The physical actuator of PA is called Variable Rate Technology (VRT) which enables the inputs, such as seeds, fertilizers, lime, and pesticides, to be applied in the rates that are accurately determined according to the needs of every management zone. The agricultural machinery has a controller which translates the prescription map on the fly and automatically varies application rates as it moves across the field.[27] This guarantees that resources are distributed where they are needed the most and also where they are not needed reducing the waste that is inherent in the conventional blanket applications. Lastly, there is the transforming frontier of PA which is the Internet of Things, Sensors and Real-Time Monitoring. This can be achieved by implementing networks of in-situ wireless sensing that constantly record the important parameters including soil moisture, temperature, nutrient content, and microclimate. These sensors send information to the cloud systems through IoT gateways and as a result, real-time monitor on the dashboard is possible and most importantly automated response can be triggered. A typical example is that water loss in soil moisture within a particular area may activate an irrigation solenoid or an increase in canopy temperature may activate a special cooling mist in a greenhouse. This completes the circle between observation and action, making PA more of a dynamic, responsive system, able to respond to variations in crop crops not only spatially, but also in real time.[28,29]

Modern Horticulture: Quality-Centric Production and Physiological Production

The contemporary horticulture does not only surpass the agronomy, but pays much attention to the physiological mechanisms of plants, especially high-value fruit, vegetables, and ornamentation, with an uncompromising value on quality as the major product.[30] The field is the key to the biological knowledge base which makes the data of PA become meaningful. At its core, there is an in-depth knowledge of the Physiology of Plants and Stress Response. The complex and intertwined processes of photosynthesis, translocation, respiration and hormonal regulation, which control growth, development and yield formation are studied by horticulturists. Most importantly, they draw a line between distress (stress that is severe, and limits the yield) and eustress (stress that is mild, tend to be positive). A wide range of quality features, most notably the synthesis of bioactive products such as anthocyanins (color) or resveratrol (antioxidant) is a result of secondary metabolism, which is often induced as a protective mechanism to controlled abiotic stress (such as moderate water deficit (regulated deficit irrigation) or light spectra). The knowledge of these cause-and-effect relationships enables the growers to utilize the environments strategically to produce desired quality results in plant metabolism without the need to reduce yield.[31 The exact environmental control is idealized by Controlled Environment Agriculture and Soilless Systems including greenhouses, vertical farms, and hydroponic/aeroponic systems. CEA separates production it of external climatic variability so that year-around growing is possible, and the optimal use of temperature, humidity, light intensity, photoperiod, and spectral quality (through LED lighting) can be controlled. Recirculating nutrient mixtures (e.g. hydroponics) and soilless substrates (e.g. rockwool, coco coir) can provide unprecedented control over the root zone, providing water and minerals in specific proportions as dictated by the particular stage of crop growth. This aspect of control renders CEA an optimal testing ground and high-worth application area of integrated PA and bioactive measures since each input

could be quantified and varied. Nonetheless, the success of any general technology depends upon Crop-Specific Management Practices. The physiological needs of a tomato are completely different to those of a strawberry, blueberry or a leafy green. An example is that the quality of tomato fruit is very sensitive to the proportions of potassium to calcium, and berry may need to be subjected to a certain amount of chilling in order to become dormant. This crop-specific vocabulary is accorded by modern horticulture, the knowledge of the phenological stages, nutrient requirements during flowering versus fruit set, during pollination, and during harvesting. It provides the answer to the question of why and when behind the question of where PA identifies, which means that technological interventions are biologically relevant and schedule so that they may have maximum effects on both the yield and the quality.[32,33]

Plant Bioactive Ingredients

Plant bioactive ingredients represents a wide range of secondary metabolites, which though not vital to primary growth and development, have important roles in plant adaptation, plant defense and interaction with the environment. They are used in agriculture, not just based on the old methods of nutrition (NPK) but rather in such a way that they directly impact on plant physiology at a hormonal and metabolic scale.[34,35] The compounds may be grouped into broad Definition and Classes (e.g., Phenolics e.g., flavonoids, lignans, stilbenes), which have anti-oxidant effects and protect against UV; Alkaloids e.g., caffeine, capsaicin), which are often used in defense against herbivores; Terpenoids e.g., carotenoids (lycopene, beta-carotene), essential oils (menthol), which provide defence, aroma and pigmentation; and Other classes.[36,37]

Table 2: Major classes of plant bioactive ingredients, their functions, and agricultural application potential

Class (Examples)	Primary Functions in Plant	Key Agricultural Application & Target Outcome
Phenolics (Flavonoids, Lignans, Stilbenes)	Antioxidants, UV protection, structural components, defense.	Elicited to enhance antioxidant capacity, color, and stress resistance in fruits/vegetables.
Alkaloids (Caffeine, Capsaicin)	Defense against herbivores, allelopathy.	Targeted boosting for medicinal/spice crops; potential role in induced pest resistance.
Terpenoids (Carotenoids, Essential oils)	Pigmentation, aroma, defense, photosynthesis.	Managed to improve color (lycopene), flavor/ aroma, and abiotic stress tolerance.
Glucosinolates	Defense compounds (e.g., in Brassicas).	Elicited for enhanced nutritional (anticancer) properties in vegetables like broccoli.
Plant Growth Regulators & Hormones (Jasmonates, Salicylates)	Internal signaling for growth, development, and stress response.	Exogenous application to prime defense systems, modulate growth, and improve fruit set.
Biostimulants (Seaweed extracts, Humic substances)	Enhance nutrient uptake, vigor, and stress tolerance.	Precision application to improve fertilizer use efficiency and homogenize crop vitality.

Synthesis of these compounds and Biosynthesis Pathways are highly regulated and frequently stimulated by environmental or biotic stimuli (elicitors). The stimulation of such pathways as shikimic acid (phenolics) or methylerythritol phosphate (terpenoids) pathways can occur.[38,39] This is the secret of their agricultural exploitation: their production can be turned on or increased by special intervention. The means of elicitation are the application of abiotic (e.g., particular light wavelengths, controlled drought stress, nutrient salts such as silicon or selenium) or biotic (e.g., shellfish, seaweed extracts, microbial consortia useful, or even compounds inherent to plants). This transforms the natural defense and adaptation system of the plant as an instrument of control improvement.[40,41]

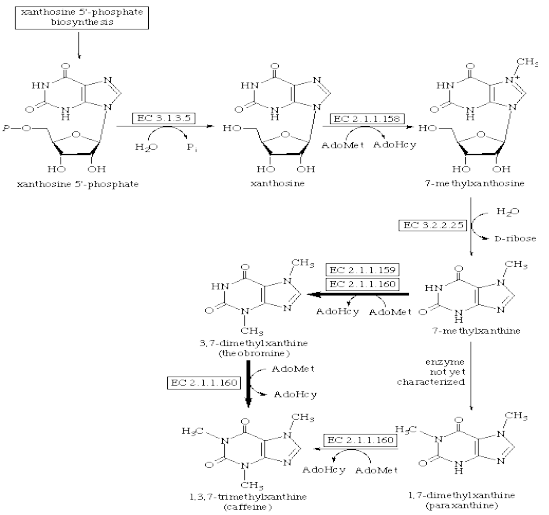

Fig. 1. Biosynthesis of Caffine by xanthine enzyme

These bioactives have a variety of Bioactivities when used exogenously: Plants Growth Regulation, Biostimulation, Stress Priming. They are not mere fertilizers but signal molecules or metabolism primers. Plant Growth Regulation implies small-scale regulation of hormonal balances (auxin, cytokinin, gibberellin) to control plant processes such as root architecture, flowering time and fruit set. Biostimulation is the improvement of nutrient uptake and use efficiency, photosynthesis rates and general plant vigor commonly observed with humic/fulvic acid use or particular protein hydrolysate use. Stress Priming (also known as acquired tolerance) is the most powerful and is the pre-treatment of the plants with a low concentration of bioactive compound (or an elicitor) to train the plant defence mechanisms. This preconditioning activates the physiological state of the plant, resulting in a quicker, more vigorous and more effective respo[42] nse of the plant to a stress in the future such as drought, salinity, or pathogen attack. Such a preventative measure can be very effective in minimizing losses of crops and preserving quality even in harsh conditions. Therefore, plant bioactives constitute an advanced, biologically-inspired toolkit to modify the plant performance, directing it toward resilience, efficiency, and biochemically-enriched structure.[43]

Synergistic Integration: Conceptual Framework

The real transformative capacity of PA, horticultural science, and bioactives does not lie in their individual implementation, but in their planned and integrated implementation. This causes a closed-loop, intelligent crop management system, in which the whole is bigger than the sum of its parts. PA is the Information-Based "Nervous System" in this context. It offers the sensory equipment (sensors, drones) to constantly monitor the condition of the crop and the surrounding environment, and the diagnostic brain (GIS, AI) to diagnose problems and discover opportunities. Horticulture provides this as the Physiological "Knowledge Base. It views the PA data in the concept of plant biology.[44,45] It identifies the reasons that may have caused the plant to be stressed (is it a potassium shortage at fruit swell? It determines the most physiologically favorable stage to act (e.g. pre-veraison in grapes to promote anthocyanin production) and when the area is in the clay-rich region to be water-logged or not (e.g. clay-rich soils). It gives the context to the crop, transforming generic data points into biological diagnosis and a strategic goal (e.g., improve antioxidant capacity in Zone B in the upcoming heatwave). Biostimulatory tool - Bioactives then carries out the prescribed intervention as the Targeted Bio-Stimulatory Tool. Rather than a generic fertilizer or pesticide, the system orders a given bioactive cocktail; say a seaweed extract full of cytokinins and betaines to a zone with heat stress, or a chitosan elicitor to a zone with high disease risk. More importantly, VRT and IoT systems allow applying these bioactives with high accuracy and in the variable rate only when required and in the accurate amount established by the combined diagnosis.

PA recognizes micro-zones of plants undergoing (or likely to be undergoing) mild and manageable stress. Horticultural knowledge ascertains that such a zone and development stage is appropriate in eliciting. An example is to activate secondary metabolism, targeting a specific zone, with a specific bioactive, without causing a yield cost to the whole field. This is to a sub-field level of controlling eustress. Second, Predictive Protection and Resource Allocation: the IoT sensors will inform about abiotic stress (e.g., soil moisture falling) earlier. After the information of the horticultural models, the system can cause a pre-emptive delivery of a priming bioactive (e.g., salicylic acid analogue) to the respective affected rows. This preparedness adds to the natural tolerance that the plant has, making the real yield less affected by the stress when it occurs in all its fullness, hence stabilizing the yield.[46,47] The resources (water, bioactives) are distributed to the regions which require prophylaxis. Third, Use Efficiency of Nutrient Ingots: When applied to sites that PA has determined that there is poor nutrient use efficiency (e.g., regions with high nitrogen reflectance, but low biomass), the plants can be encouraged to utilize better the available nutrients in their environments, closing yield gaps and enhancing uniformity. This forms a virtuous cycle since an improvement in the health of the plants results in the increased homogeneity of the PA sensor measurements. Lastly, Dynamic Quality Optimization: In the high-value contract where a certain nutraceutical content is required, PA may track spectral indices that are associated with bioactive concentration (e.g.,anthocyanin reflectance index). With harvest at hand, when some blocks underperform against target values, horticultural expertise may be used to apply a last and focused elicitor treatment to those underperforming blocks,

which will result into quality consistency and attainment of high market specifications. Finally, this unified model shifts agriculture to a form that is more reactive and input-based to a model, which focuses on plant-physiology.[48,49] The nervous system of the PA senses, the body of knowledge of horticultural knowledge understands and counseleth, and the bioactive tools implement the specifics of physiological intervention. Such synergy is bound to overcome the perceived trade-off between yield and quality, and result in sustainable intensification to ensure the future food security and nutritional needs are met.[50]

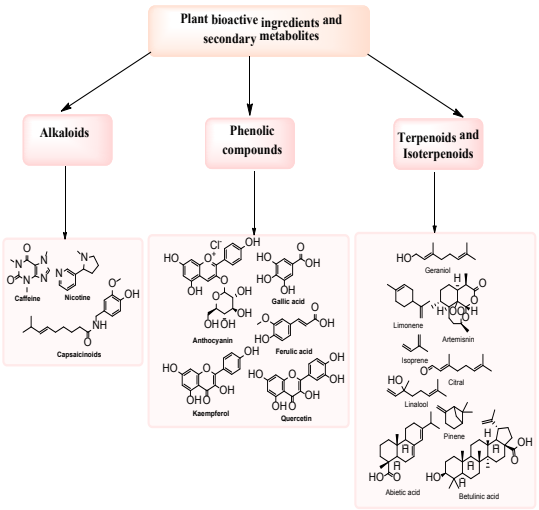

Fig. 2. Classification plant bioactive ingredients

The Convergence: mechanisms of synergistic integration

The real healing power of this triad is not in their application separately, but in their conscious combination. This brings about a closed loop intelligent management system in which data drives accurate interventions to control plant physiology, and the biochemical output is used to inform more accurate interventions. In this section, the mechanisms that allow this synergy to happen are disected starting with sensing and mapping and on to active optimization and feedback.

Mapping and Managing the Variability of Bioactive compounds PA

One of the essential problems when manufacturing plant-based bioactive components is their spatial and temporal variability within a stand of crop. The conventional bulk harvesting method homogenizes this variability, which is usually diluted in potency. Precision Agriculture offers the toolkit to map, comprehend and treat this heterogeneity as an asset, but not a liability.[51,52]

Spectral sensing for predicting phytochemical content

The backbone of such integration is the real time estimation of bioactive compounds non-destructively with the help of spectral sensing. The interaction of light and plants takes place at different wavelengths (400-2500nm) and the spectrophotometric patterns of their reflectance are the unique fingerprints that rely on the biochemical composition. Sophisticated methods of analysis remove the distance between spectral data and phytochemical concentration.[53,54] Detailed canopy reflectance data are obtained by hyperspectral and multispectral sensors on UAVs, or tractors, or satellites. There are specific compounds that have key spectral regions: e.g. anthocyanins at the green range (in the 550nm range), chlorophyll and nitrogen status at the red-edge (in the 700-750nm range), and water content and broad biochemical bonds (C-H, O-H, N-H) at the short-wave infrared (SWIR, 1000-2500nm). This connection is created through chemometrics.[55,56,57] Simultaneous spectral measurements are combined with ground-truthing, in which the samples of the plant tissue are scrutinized in the lab through HPLC or GC-MS to determine the precise amount of a specific compound. Algorithms of machine learning (e.g., Partial Least Squares Regression, Random Forest, Neural Networks) are then trained to come up with robust calibration models. Such models can then be used to forecast the concentration of target compounds (e.g. curcumin in turmeric, capsaicin in peppers, constituents of essential oils in herbs) in a wide field of spectral data alone. This allows the generation of high resolution phytochemical maps. Not only can a grower see in which plants are stressed or in which plants are actively growing, but also in which areas of the field there are high therapeutic or nutritional density. This shifts the management to a bioactivity-centric perspective as opposed to a biomass-centric perspective.

Zoning management based on biochemical phenotypes

The spectral sensing phytochemical maps are used to help switch between uniform field management to the biochemical phenotype, or zoning- based field management of plants sharing bioactive compound profiles. GIS software groups the

habitat with comparable forecasted phytochemical rates into separate management groups.[58] A vineyard can be given as an example, though divided into high, medium, and low anthocyanin/polyphenol zones. This is the most immediate application. The harvesting can be planned and implemented zone-wise. Zones with high potency may be harvested singly (to produce premium lines of products e.g. single-origin or high-potency labeled extracts), low-potency zones may be sold into the regular markets. This results in the optimization of the crop and stability of nutraceutical producers. Out of harvest, such areas inform focused agronomic interventions. An area that has low-than-preferred bioactive matter can be subjected to a certain precision horticulture treatment (e.g. customized irrigation or nutrient spray), and induce production, which will be detailed in the following section. When variability is mapped, precision horticulture offers the physiological levers to act upon to manipulate plant secondary metabolism in an active manner. The aim is to use controlled, focused stresses or stimuli to upregulate biosynthetic pathways without causing a major reduction in primary yield- a principle referred to as "eustress." Secondary metabolites are a large number of bioactive compounds whose synthesis is involved in the defense against environmental stress. These stresses can be administered in a controlled dose-specific way using precision technologies. LED lights enable the precise spectral control in Controlled Environment Agriculture. Presentation of plants to a certain wavelength can significantly change the phytochemistry. An example is UV-B radiation, which is a very strong inducer of polyphenols and flavonoids (e.g. in basil and lettuce). The inclusion of the far-red light can affect morphology and secondary metabolism. PA data of actual plant response can dynamically regulate "light recipes" to optimize a particular compound. Precise drip or micro-sprinkler systems that apply strategic water stress have been shown to raise the concentration of essential oils, phenolic compounds, and antioxidants in plants such as grapes, olives and aromatic herbs by applying strategic water stress at certain phenological stages in the plant. The soil moisture sensors and evapotranspiration models are used to make sure that the stress is accurately regulated so as to induce metabolite production without leading to irreparable harm or loss in yield. Precision elicitors can also be mild temperature changes or controlled exposures to positive gases (e.g. ozone, CO_2 enrichment) directed by sensor networks.[59]

Precision nutrient management to enhance secondary metabolites

The trade-off between primary (biomass) and secondary metabolite production directly depends on nutrient availability. Precision nutrition adjusts this balance positively by increasing supply. The role of nitrogen (N) is essential; high N nitrogen levels enhance vegetative growth, however, distorting secondary metabolites. Regulated, low N level, particularly at advanced stages, tends to stimulate the synthesis of the phenolic compounds and alkaloids. Equally, the presence of phosphorus, potassium, sulfur and micronutrients such as selenium can serve as a signal or co-factor during certain biosynthetic pathways. With VRT, application of fertilizers can be done differently depending on the zoning of both desired bioactive targets and yield potential. A zone with a high bioactive potential will not have the same N:K ratio as one applied in a zone with the highest possible fresh weight yield. Strong elicitors of secondary metabolism include plant growth regulators (PGRs), biostimulants (e.g., jasmonic acid, salicylic acid, seaweed extracts), etc. They can be induced selectively on a zone-by-zone basis by their foliar application through sprayers fitted with VRT. Using the phytochemical maps, a low-potency zone may be directed using an accurate dose of an elicitor (e.g., methyl jasmonate) to stimulate pathways associated with defence, and thus increase the synthesis of desired compounds such as terpenoids or alkaloids. It eliminates the need to apply to areas high in performance, thereby reducing the input expenses and eliminating possible phytotoxicity.

Bioactive ingredients as indicators and targets for PA

It is symbiotic in nature. Similarly to the bioactive content of a product being measured and affected by PA tools, the phytochemical profile of a plant is a complex, inherent biosensor, which can be used to gain profound insights into plant conditioning that can be used to refine PA decision-making. Conventional PA uses indirect measures of stress (e.g., chlorophyll fluorescence, canopy temperature). Direct, mechanistic biomarkers are provided by specific bioactive compounds. The buildup of some antioxidants (e.g., ascorbate,

glutathione) or stress-specific products may indicate the development of biotic or abiotic stress prior to the emergence of any noticeable symptoms or loss of any substantial quantity of biomass. The pre-symptomatic intervention is possible through spectral detection of these compounds. Various stressors cause different phytochemical signatures. Drought could increase the levels of abscisic acid (ABA) and proline, and herbivory could induce quick production of jasmonates and specific volatile organic compounds (VOC).

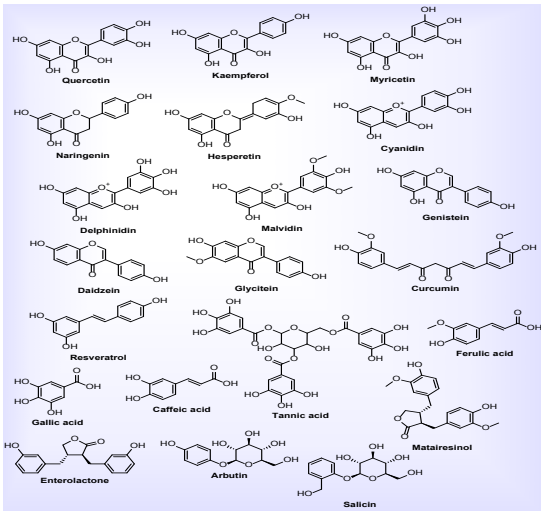

Fig. 3. Chemical Compound and its Active Ingredients

The diagnosis of stress type and degree using such spectral-biochemical signatures enables the PA to be transformed into a diagnostic and predictive system as opposed to a reactive one. The revolution is the integration of the breeding of plants in nutraceutical and functional food markets. Breeders can non-destructively and in a brief period time, screen thousands of field-grown genotypes with PA technologies especially UAV-based spectral imaging to select genotypes according to agronomic factors (biomass, height) and biochemical factors (estimated phytochemical content). This generates gigabank, spatially-referenced, genotype to biochemical phenotype real-field datasets. The breeders are able to establish plants that not only produce well but also produce desired bioactive elements in high amounts over a given regime of management (GxExM interaction). PA data can be used to find these elite chemotypes in the context of a dissimilar breeding population. Genomic selection models take input in the spatial and temporal information of phytochemical expression related to environmental and management information. This speeds up the process by which novel cultivars that are optimized to produce bioactives are developed in precision agri-horticulture systems so that genetic capability is not wasted as a result of agricultural blight.

This theoretical compatibility of precision agriculture, horticulture and bioactive compound management is operationalized by a collection of convergent technologies and new methodology paradigms. It is a change in the discrete tools towards a unified, cyber-physical system where biological processes can be tracked, comprehended and intervened with a precision and purported intent never before seen. This portion describes the fundamental technological pipelines and sophisticated procedures that help in transforming the theoretical synergy into practical farm management and research procedures.

The digital pipeline: from sensor data to bioactive optimization

A unified flow of information between the field and the cloud and back to the actuator is the key to the inner workings of the integrated system. This pipeline will turn raw environmental and plant data to predictive knowledge and, eventually, prescriptive management actions that will optimize the yield and phytochemical content. Phenotyping traditional is a bottleneck. A combination of HTP platforms and metabolomic analysis forms a potent engine that may find the correlation between plant structure, physiology, and biochemistry in scale. This is non-destructive non-phenotypic, sensor-based systems that are automated. In the field this is done through UAVs or ground rovers with multi-sensor arrays: RGB cameras to determine morphology, multispectral/ hyperspectral sensors to determine physiology and biochemistry, LiDAR to obtain 3D structure, and thermal cameras to detect stress. Controlled environments have conveyor-based systems which have fixed sensors to carry out similar functions. The result is a product of terabytes of geotagged images and spectral data of the phenotype (the observed characteristics) of all the plants or plots. The important connection is making a chemometric bridge. A representative tissue sample is determined among the HTP-screened population using spectral signatures. These are subjected to stringent metabolomic profiling with such methods as Liquid chromatography-Mass Spectrometry (LC-MS) or Gas chromatography-Mass Spectrometry

(GC-MS). This gives a detailed, quantitative picture of hundreds or thousands of primary and secondary metabolites -the biochemical phenotype. The high-dimensional data (spectra, images) of phenotypes is convoluted with the high-dimensional data (metabolite concentrations) of biochemistry. Models are trained using advanced machine learning (e.g. deep convolutional neural networks with image data, partial least squares discriminant analysis with spectral data). The goal is to find out what spectral bands or vegetation indices or image identifiers are predictive of certain, useful metabolites. Trained and verified, these models can be used to forecast the concentration of every metabolite in the field only using the spectral/image signature of that individual plant, in effect, producing a real time, spatially explicit map of the metabolome. One of the layers is the HTP-metabolomics connection. The entire strength comes out of committing multi-omics information into the spatial and temporal framework outlined by PA to generate a multi-scale interpretation of the genotype-to-phenotype spectrum. PA gives the geospatial container- the where and when. In this container, deposited is stratified biological information: The genetic blueprint (DNA sequence) of the cultivars being cultured, usually by genotyping-by-sequencing. Gene expression of plants in various management zones or receiving various treatments of precision elicitation, and how to identify which of the biosynthetic pathways is active.

This combination enables scientists and agronomists to transcend of correlation to mechanistic knowledge. To illustrate, studying plants in a high-polyphenol area, it is possible to observe not only increased polyphenols (metabolomics), but also the increased expression of phenylalanine ammonia-lyase (PAL) and chalcone synthase (transcriptomics) genes in the given environmental conditions (soil moisture, light exposure) recorded by the PA sensors. This allows the precision horticulture intervention (e.g., a certain light treatment) to be designed that is known to trigger the transcriptional cascade to produce the desired metabolite. This structure enhances the breeding of the molecules. Using the correlation of spatial yield and metabolite data with genomic markers, breeders are able to recognize Quantitative Trait Loci (QTLs) or genes linked to high biochemical functioning in real-world and variable settings. This results into cultivars that are specifically bred with stability and responsiveness in precise management systems. The final target is the multi-objective optimization. This needs advanced modeling with the ability to predict the usually competing results of biomass build up and secondary metabolite synthesis under varying management conditions. Two complementary methods are employed. Crop models (process-based e.g. modified versions of APSIM or DSSAT) have secondary metabolism sub-models added. These models employ physiological principles that model the partitioning of water, nitrogen and light into the growth and defense pathways. They are effective in investigating possible scenarios of what-if (e.g., what will happen when there is a 20% water deficit at flowering to anthocyanin yield?). Machine learning models (e.g., random forest, gradient boosting) are data-driven and are trained based on historical and real-time data of the digital pipeline. They obtain non-linear, intricate correlations between sensor inputs, management interventions and the two outputs of biomass and bioactive concentration. When these models are combined with real-time data streams, this results in the idea of a so-called digital twin of a field or greenhouse. The sensor data is constantly updated in this virtual replica. Simulations with this twin may be performed by the grower or by an AI agent: What will be the predicted effect of this nutrient recipe implemented with VRT in Zone A and this water deficit in Zone B on total dry yield and total flavonoid yield per hectare? The model gives optimum prescription maps that trade off goals, possibly 5 percent biomass in order to increase bioactive potency by 25 percent, based on priorities in the market. The prescriptive maps, created as a result of the digital pipeline, are senseless without the technological tool, which can implement them with accuracy. The next frontier is to go beyond bulk application to specific, effective and smart systems of delivery of the inputs that control plant health and direct metabolism. Mobilisation of elicitors (e.g., jasmonic acid, chitosan, salicylic acid) to enhance secondary metabolites is not very efficient because it can be degraded, lost by runoff and taken up non-specifically. Nanotechnology provides radical mode of delivery. Elicitors may be entrapped in or conjugated to nano-scaffolds like polymeric nanoparticles (e.g., chitosan, alginate), liposomes or silica nanoparticles. These carriers are designed to possess certain properties. Various advantages of this nano-encapsulation can be used in the management of bioactive in[61] Coats

the elicitor to prevent early degradation by sunlight or microbes. Controlled Release: This is used to release the elicitor over time in a slow sustained manner that gives the induction signal a long-term and not transient signal. The nanoparticles can be structured to enhance easier entry via stomata or the cuticle and can be systemically translocated in the plant. In the future, surface functionalization of nanoparticles with specific ligands may enable the targeted delivery of nanoparticles to specific tissues of plants (e.g. glandular trichomes where essential oils are stored).

The use of nano-elicitor is made a precision tool. The multispectral scan of a zone using a UAV reveals a low terpenoid zone. The prescription map is created and a sprayer having VRT and possibly even nozzle level control dispenses a nano-elicitor formulation to that particular zone only.[62,63] This results in reduced doses, which are less expensive and with less environmental burden compared to more potent and localized biochemical response and is more efficient. The principles of VRT and sensing are currently being applied to the biological inputs which are key to the sustainable production of bioactive ingredients of high-quality and free of residues. The need of intervention is mapped with the use of PA technologies. Hyperspectral imaging is able to measure the initial phases of fungal disease (when it is not visible) based on slight variations in leaf reflectance. Machine vision cameras can recognize species and locations of weeds. In the same way, areas with low plant vitality (based on NDVI maps) may be identified and marked as biostimulant supported. Precision Application Technologies: In the case of biocontrol, this refers to the application of beneficial insects, fungi or bacteria to the exact location of pest or disease occurrence.[64,65] UAVs have the capability of dropping predatory mite sachets on individual hotspots. Sprayers can apply fungal biocontrol agents (i.e. Trichoderma) or bacterial agents (i.e. Bacillus thuringiensis) to only infected places, leaving beneficial insects elsewhere. In the case of biostimulants (e.g., seaweed extracts, humic substances, beneficial microorganisms such as plant growth promoting rhizobacteria),[66] VRT sprayers or in-line fertilizers can spray the products onto zones which the sensor data indicates are experiencing stress or low vitality. This enhances plant defense and secondary metabolism of the stressed regions homogenizing the quality of fields and limiting the transmission of stress signals that could have an impact on the surrounding plants. Dynamic Driving. The state of the art systems are closed-loop. As an instance, a system of pheromone traps and automated insect counters or spore traps with DNA-based detection of any pathogen can deliver real time pest/pressure information. This information gets directly to the decision system, which automatically causes a precision spray application of a biocontrol agent to occur only when an economic threshold is exceeded within a given geo-located block.

Challenges and future perspectives

Despite its transformative potential, the synergistic integration of precision agriculture, horticulture, and bioactive ingredient optimization faces significant multi-dimensional hurdles. Acknowledging these challenges is crucial for directing research, investment, and policy. Simultaneously, mapping clear future pathways is essential to translate this promising paradigm from experimental plots and controlled environments into widespread, commercially viable, and sustainable practice.

Table 3: Key challenges and future research directions for the integrated framework

Challenge Category	Specific Hurdles	Future Research & Innovation Directions
Technical & Analytical	High cost/complexity of sensor-metabolomics platforms; data fusion & interoperability issues.	Develop low-cost, real-time phytochemical sensors; establish open data standards and APIs.
Biological & Agronomic	Complex GxExM interactions; managing yield-quality trade-offs.	Build large-scale multi-location datasets; advance AI for multi-objective optimization.
Technological Delivery	Inefficient delivery and degradation of elicitors; non-targeted application.	Engineer nano-delivery systems for protected, controlled release of elicitors.
Systemic Integration	Disconnect from broader bioeconomy; energy footprint of high-tech systems.	Integrate with circular bioeconomy models (waste-to-value); conduct full Lifecycle Assessments (LCA).
Policy & Adoption	Gap between agri-tech and nutraceutical industries; need for skilled labor.	Foster public-private consortia; create certification standards; revolutionize agricultural education.

Technical and analytical hurdles

The sophistication of technology that makes such integration possible is also the main problem that prevents its adoption as there are issues of cost, complication, and data management. The pipeline which is at the basis of spectral sensing connecting to metabolomic validation is costly. The high-resolution hyperspectral sensors and UAVs such as the requirement to carry them are a significant capital expenditure that many small and medium-scale producers can not afford, yet many specialty crops that grow best under this method are of high value. Moreover, metabolomic ground-truthing necessary to construct strong calibration models entails the costly, destructive laboratory measurements with high-performance technologies in use (LC-MS/GC-MS) and professional skills.[67,68] This presents a Catch-22, in that strong models are required to justify the sensor investment, but the cost of constructing those models is too high without infrastructure in place to support it. The digital literacy and technical infrastructure required to manage armies of robots, drones, and sensor networks, as well as process terabytes of multi-modal data, is currently a high requirement which is often lacking in most of the agricultural areas. The interoperating system produces heterogeneous streams of data: spectral imagery, soil sensor records, weather records, genomic sequence, transcriptomic profile, and metabolomic records. Each stream may usually exist in proprietary formats in different spatial and temporal scales. To be able to integrate these into a coherent, analyzable entity is a mammoth informatics task. Universal data standards of agricultural biochemical phenotyping are in dire need. What is the geotag method of the metabolomic profile of a specific plant pixel in a UAV image? To what extent are data on terpenoid expression of a greenhouse trial interoperable with field data of another sensor brand? Lack of standard ontologies and Open Application Programming Interfaces (APIs) results in data silos, which impedes the creation of universal AI models and slows the progress of science due to low data sharability and reproducibility. In addition to the hardware and software, there are deep-seated challenges presented in the nature of plant biology and agricultural systems. The most typical demonstration of GxExM is the production of bioactive compounds. A cultivar (G) might react to a lack of water (M1) at a cool climate (E1), but have a different reaction to the same lack of water (M2) at a hot climate (E2). Such a three-way interaction is incredibly more complicated than the GxE interactions that are handled in the traditional yield-based PA. Creation of predictive models needs huge, multi-location, multi-year data which vary systematically across management inputs between genotypes in different environments. Prescriptions that are universally applicable are hard to make because of the combinatorial explosion of the number of possible scenarios. An AI model trained based on data of a herb farm in the Mediterranean will fail disastrously in a temperate climate without substantial recalibration, requiring localized model training that once more increases the cost and complexity requirements. The agronomic issue of central interest is the negative correlation between primary (growth, biomass yield) and secondary metabolism (production of bioactive compounds) most of the time. Stressing fruit with water can shrink fruit; nutrient limitation enhances alkaloid growth can retard the growth of plants. The multi-objective optimization models above are necessarily required, yet they have to deal with this inherent biological trade-off.[69,70] The economic optimum may not be always the biochemical or biophysical maximum. The difficulty lies in determining which level of management stress is the sweet spot, usually a mild and focused stress at a particular phenological stage, that will lead to the maximum economic value of the crop which is a combination of the volume of biomass and the concentration of desirable ingredients in that biomass. This value proposition has to be defined and communicated to the growers who are conventionally paid by weight, which is a big challenge.

RESULT AND DISCUSSION

To handle these challenges, it is necessary to conduct research and development efforts in a number of areas that are critical. The future will be in the transfer of indirect spectral prediction into direct low cost sensing. Two major studies are miniaturization and field deployable analytical devices. This includes advancements. Creating rugged, inexpensive, handheld or attached to simple robots hyperspectral or Raman spectrometers. Producing synthetic biosensors or nanoparticle-based probes that would be capable of binding to a class of compounds (e.g., flavonoids) and produce an optical or electrical signal which can be read by a rudimentary device. Chemical sensor arrays capable

of profiling volatile organic compound imprints which are commonly direct measures of certain metabolic conditions and bioactive profiles allowing real-time measurement of crop biochemical condition. The new generation AI should grow to be more prescriptive and adaptive rather than merely predictive. Among the key directions are: Replacing black-box models that make predictions with models that can make inferences on causal relationship as part of the GxExM framework, and why a particular treatment did increase a compound. This creates trust and biological awareness. Applying the RL algorithms which provide the system with an opportunity to acquire the best management strategy, which is more likely to promote joint interaction of the system with the crop in a greenhouse or field, dynamically adapting the inputs to the most efficient use of resources and a combined rewarding function comprising the yield, bioactive content and resource use efficiency. Creating new, site-specific elicitation protocols or even new, harmless biostimulant molecules designed using AI to respond to genomic and metabolomic information to produce the desired pathway. The final sustainability examination of this triad is to test it by incorporating it into larger systems. The research should aim at Selecting PA to sort out the plant biomass that contains a specific high concentration of bioactives that cannot be sold in the main market (e.g. misshapen fruit, pruning residues) to extract efficiently in decentralised biorefineries to generate additional sources of revenue and avoid waste. Application of the blockchain technology in order to trace the biochemical profile of a batch within a particular zone of management during the processing stage to the end product (nutraceutical, functional food). This certifies high quality, transparency and may result in more equitable distribution of values to the grower who invested in quality improving practices. Implementing thorough LCAs to measure the actual environmental footprint of such high-tech systems, so that water and nutrient use efficiency gains do not lead to the expenditure of the embodied energy of sensor construction and data processing, and to implement the development of truly sustainable protocols.

CONCLUSION

It has achieved a well-purposed vision of high-value plant production in the future: the synergistic combination of Precision Agriculture, Advanced Horticulture, and Bioactive Ingredient Optimization. This synergy is iterative and mechanical. Precision Agriculture offers high-resolution spatial and temporal data canvas, which is spectral sensing to map the diversity of plant physiology and phytochemical content. Precision Horticulture uses this map to deliver dose-specific elicitors-whether in the form of water deficits, spectrally selective light or nano-encapsulated signaling molecules-to influence actively the production of plant secondary metabolism. The resulting Bioactive Ingredients, in turn, provide the direct biomarkers of the plant status, as the PA algorithms are refined and provide a valuable trait to breeding programs based on the high-throughput, field-based phenotyping. Results of vineyards maximizing polyphenols, regulated conditions to achieve optimal light to certain antioxidants and studies that combine metabolomics and UAV sensing indicate that this triad has the potential to shift mass production into fine-tuning biochemical production. The future lies not in technological proliferation but in smart convergence and system thinking. It involves the de-silicing of disciplinary boundaries between agronomists, plant physiologists, data scientists and chemists. The goal is the creation of “Phytochemically-Optimized Production Systems"-closed-loop, adaptive agricultural systems which address the biochemical profile of the crop as a primary, controllable output. These systems will, by implication, have AI-controlled virtual twins that continually simulate results, autonomous machines controlled by prescriptive maps, and passports protected by blockchain that contain the provenance and potency information of each batch, to an ever-increasing skeptical market. The maximization of tonnes per hectare is replaced by the maximization of nutritional or therapeutic value per unit of resource input a paradigm that is consistent with the pressing demands of both planetary and human health.

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Conflict of interest

The author declare that we have no conflict of interest.

REFERENCES

1. Aasim, M.; Khaliq, A., & Hussain, S., Artificial intelligence in precision agriculture: A systematic review. *Computers and Electronics in Agriculture*., **2022**, *202*, 107337.
2. Ali, S.; Khan, N., & Tang, Y., Elicitation of secondary metabolites in plants using nanomaterials: A Review. *Environmental Chemistry Letters*., **2022**, *20*(4), 2597–2626.
3. Backhaus, A.; Baur, R., & Ladewig, E., Hyperspectral imaging for high-throughput plant phenotyping in controlled and field environments., *Remote Sensing*., **2021**, *13*(11), 2236.
4. Bastías, R. M., & Corelli-Grappadelli, L., Light quality management in fruit orchards: Physiological and technological aspects., *Chilean Journal of Agricultural Research*., **2012**, *72*(4), 574–581.
5. Bhandari, M., & Shahi, N. C., Internet of Things (IoT) for real-time monitoring in precision agriculture: A Review. *Journal of Biosystems Engineering*., **2021**, *46*(3), 237–254.
6. Biancolillo, A., & Marini, F., Chemometric methods for spectroscopy-based plant phenotyping., *Chemometrics and Intelligent Laboratory Systems*., **2018**, *178*, 60–69.
7. Börner, A., & Khlestkina, E. K., Genetic resources for enhancing bioactive compounds in crops., *Frontiers in Plant Science*., **2019**, *10*, 977.
8. Bulgari, R.; Franzoni, G., & Ferrante, A., Biostimulants application in horticultural crops under abiotic stress conditions., *Agronomy*., **2019**, *9*(6), 306.
9. Challa, S., & Neelapu, N. R. R., Precision farming: The future of Indian agriculture., *J. of Pharmacognosy and Phytochemistry*., **2021**, *10*(1), 1895–1901.
10. Chen, T., & Li, C., Machine learning for predicting crop quality from hyperspectral imagery: A case study on grape anthocyanins., *Computers and Electronics in Agriculture*., **2020**, *177*, 105692.
11. Cobo, M. J.; López-Herrera, A. G.; Herrera-Viedma, E., & Herrera, F., Science mapping software tools: Review, analysis, and cooperative study among tools., *Journal of the American Society for Information Science and Technology*., **2011**, *62*(7), 1382–1402.
12. Colaço, A. F., & Molin, J. P., Variable rate fertilization in citrus: A Review of spatial variability assessment and management., *Precision Agriculture*., **2022**, *23*(1), 1–24.
13. Colla, G., & Rouphael, Y., Biostimulants in agriculture., *Frontiers in Plant Science*., **2020**, *11*, 40.
14. D'Amico, M.; Frisullo, S., & Cirillo, C., Precision viticulture and oenology: Advanced tools for managing grape quality., *Foods*., **2023**, *12*(4), 854.
15. De Pascale, S.; Maggio, A., & Barbieri, G. Plant biostimulants in horticulture: An overview., *Horticulturae*., **2018**, *4*(4), 28.
16. De Simone, L., & Rossi, F. Sustainable intensification in agriculture: A Review of concepts and operational definitions., *Land Use Policy*., **2021**, *109*, 105669.
17. Dörner, J., & Zúñiga, F. Soil health and precision agriculture: A synergistic approach for sustainable production., *Soil Systems*., **2021**, *5*(3), 46.
18. du Jardin, P. Plant biostimulants: Definition, concept, main categories and regulation., *Scientia Horticulturae*., **2015**, *196*, 3–14.
19. Elarab, M.; Ticlavilca, A. M., & Torres-Rua, A. F., Estimating chlorophyll with thermal and broadband multispectral high resolution imagery from an unmanned aerial system using relevance vector machines for precision agriculture., *International Journal of Applied Earth Observation and Geoinformation*., **2015**, *43*, 32–42.
20. Fahlgren, N.; Gehan, M. A., & Baxter, I., Lights, camera, action: High-throughput plant phenotyping is ready for a close-up., *Current Opinion in Plant Biology*., **2015**, *24*, 93–99.
21. FAO., The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations., **2017**.
22. Ferrante, A., & Maggiore, T., Postharvest losses of fruits and vegetables: Causes and strategies for reduction. *Italian Journal of Agronomy*., **2020**, *15*(2), 155–162.
23. Gebbers, R., & Adamchuk, V. I., Precision agriculture and food security., *Science*., **2010**, *327*(5967), 828–831.
24. Godfray, H. C. J.; Beddington, J. R.; Crute, I. R.; Haddad, L.; Lawrence, D.; Muir, J. F.; ... & Toulmin, C., Food security: The challenge of feeding 9 billion people., *Science*., **2010**, *327*(5967), 812–818.

25. Gosal, S. S., & Wani, S. H., Accelerated plant breeding for nutraceuticals and functional foods. Springer International Publishing., **2020**.
26. Harrill, J. R., & Vandeven, M., Digital twins in agriculture: A Review of concepts and applications., *AgriEngineering.*, **2023**, *5*(1), 356–374.
27. Hawkesford, M. J., & Griffiths, S., Exploiting genetic variation in nitrogen use efficiency for sustainable wheat production., *Journal of Experimental Botany.*, **2019**, *70*(7), 1929–1939.
28. He, L., & Li, Y., Reinforcement learning for greenhouse climate control: A Review. *Biosystems Engineering.*, **2022**, *223*, 58–73.
29. Herzig, P., & Backhaus, A., Data fusion in precision agriculture: A Review. *Remote Sensing.,* **2021**, *13*(23), 4877.
30. Hunter, M. C., Smith, R. G., Schipanski, M. E., Atwood, L. W., & Mortensen, D. A. (2017). Agriculture in 2050: Recalibrating targets for sustainable intensification., *BioScience.*, **2021**, *67*(4), 386–391.
31. Jansen, M., & van Ittersum, M. K. The dilemma of "sustainable intensification". *Agricultural Systems.*, **2020**, *185*, 102944.
32. Jones, J. B., Complete guide for growing plants hydroponically. CRC Press., **2014**.
33. Kamilaris, A.; Kartakoullis, A., & Prenafeta-Boldú, F. X. A Review on the practice of big data analysis in agriculture., *Computers and Electronics in Agriculture.*, **2017**, *143*, 23–37.
34. Kazmi, D. H., & Raza, S. A. Nanotechnology: A novel tool for precision delivery of agrochemicals., *Journal of Plant Growth Regulation.*, **2022**, *41*(3), 983–1000.
35. Khaki, S., & Wang, L. Crop yield prediction using deep neural networks., *Frontiers in Plant Science.*, **2019**, *10*, 621.
36. Kole, C.; Muthamilarasan, M., & Henry, R., Application of genomics-assisted breeding for generation of climate resilient crops: Progress and prospects., *Frontiers in Plant Science.*, **2015**, *6*, 563.
37. Kumar, R., & Sharma, O. P., Plant secondary metabolites: Their food and therapeutic importance. Springer., **2020**.
38. Li, L.; Zhang, Q., & Huang, D., A Review of imaging techniques for plant phenotyping., *Sensors.*, **2014**, *14*(11), 20078–20111.
39. Lobell, D. B., Schlenker, W., & Costa-Roberts, J., *Climate trends and global crop production since.,* 1980. Science., **2011**, *333*(6042), 616–620.
40. Lowry, G. V., Avellan, A., & Gilbertson, L. M., Opportunities and challenges for nanotechnology in the agri-tech revolution., *Nature Nanotechnology.,* **2019**, *14*(6), 517–522.
41. Maes, W. H., & Steppe, K., Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture., *Trends in Plant Science.*, **2019**, *24*(2), 152–164.
42. Moghimi, A.; Yang, C., & Miller, M. E., A novel approach to assess the quality of blueberries using hyperspectral imaging., *Postharvest Biology and Technology.*, **2020**, *169*, 111306.
43. Murchie, E. H., & Niyogi, K. K., Manipulation of photoprotection to improve plant photosynthesis., *Plant Physiology.*, **2011**, *155*(1), 86–92.
44. Nhamo, L.; Mabhaudhi, T., & Magombeyi, M., Digital and precision agriculture for food and nutrition security in a changing climate., *Frontiers in Sustainable Food Systems.*, **2022**, *6*, 872706.
45. Pagola, M., & Ortiz, R., Spectral indices for the estimation of crop biophysical and biochemical parameters: A Review. *Remote Sensing.,* **2021**, *13*(20), 4059.
46. Pretty, J., & Bharucha, Z. P., Sustainable intensification in agricultural systems., *Annals of Botany.*, **2014**, *114*(8), 1571–1596.
47. Reynolds, M., & Langridge, P., Physiological breeding., *Current Opinion in Plant Biology.*, **2016**, *31*, 162–171.
48. Rouphael, Y., & Colla, G., Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications., *Agronomy.*, **2020**, *10*(10), 1461.
49. Sams, C. E., Preharvest factors affecting postharvest quality. In Postharvest physiology and biochemistry of fruits and vegetables., **2020**, 27-48. Woodhead Publishing.
50. Schumann, A. W., & Zaman, Q. U. Precision agriculture for citrus. UF/IFAS Extension., **2019**.
51. Shah, S. H.; Angel, Y., & Houborg, R., Leaf pigment retrieval using the PROSAIL model: A Review. *Remote Sensing.*, **2021**, *13*(13), 2460.
52. Sharma, P., & Sangwan, N. S., Elicitation: A biotechnological tool for enhancement of secondary metabolites in aromatic plants., *Journal of Applied Research on Medicinal and Aromatic Plants.*, **2022**, *30*, 100385.

53. Smith, P., & Gregory, P. J. Climate change and sustainable food production., *Proceedings of the Nutrition Society*., **2013**, *72*(1), 21–28.
54. The Royal Society. Reaping the benefits: Science and the sustainable intensification of global agriculture. The Royal Society., **2009**.
55. Tilman, D.; Balzer, C.; Hill, J., & Befort, B. L., Global food demand and the sustainable intensification of agriculture., *Proceedings of the National Academy of Sciences*., **2011**, *108*(50), 20260–20264.
56. Tixier, M. H., & Lavialle, O., A Review of variable rate technology for fertilization and plant protection., *Smart Agricultural Technology*., **2021**, *1*, 100009.
57. Toscano, S.; Ferrante, A., & Romano, D., Postharvest quality of leafy vegetables as affected by preharvest factors., *Horticulturae*., **2019**, *5*(4), 77.
58. Van Evert, F. K.; Gaitán-Cremaschi, D.; Fountas, S., & Kempenaar, C., Can precision agriculture increase the profitability and sustainability of the production of potatoes and olives? Sustainability., **2017**, *9*(10), 1863.
59. Walter, A.; Finger, R.; Huber, R., & Buchmann, N., Smart farming is key to developing sustainable agriculture., *Proceedings of the National Academy of Sciences*., **2017**, *114*(24), 6148–6150.
60. Wang, L., & Li, X., Multi-omics integration for understanding plant responses to environmental stresses., *Molecular Plant*., **2020**, *13*(8), 1078–1080.
61. Wheeler, T., & Von Braun, J., Climate change impacts on global food security., *Science*., **2013**, *341*(6145), 508–513.
62. Wolfert, S.; Ge, L.; Verdouw, C., & Bogaardt, M. J., Big data in smart farming—A Review. *Agricultural Systems*., **2017**, *153*, 69–80.
63. Xie, C., & Yang, C. A Review on plant high-throughput phenotyping traits using UAV-based sensors., *Computers and Electronics in Agriculture*., **2020**, *178*, 105731.
64. Yang, C.; Everitt, J. H., & Bradford, J. M., Comparison of QuickBird satellite imagery and airborne imagery for mapping grain sorghum yield patterns., *Precision Agriculture*., **2008**, *9*(4), 201–215.
65. Yong, J. W. H.; Ng, Y. F., & Tan, S. N. The chemical composition and biological properties of coconut *(Cocos nucifera L.)* water., *Molecules*., **2020**, *25*(19), 4438.
66. Zhang, C., & Kovacs, J. M., The application of small unmanned aerial systems for precision agriculture: A Review. *Precision Agriculture*., **2012**, *13*(6), 693–712.
67. Zhao, C.; Zhang, Y.; Du, J., & Zhang, Q., Crop phenomics: Current status and perspectives., *Frontiers in Plant Science*., **2019**, *10*, 714.
68. Zhu, J. K., Abiotic stress signaling and responses in plants., *Cell*., **2016**, *167*(2), 313–324.
69. Zörb, C.; Geilfus, C. M., & Dietz, K. J., Salinity and crop yield., *Plant Biology*., **2019**, *21*(S1), 31–38.
70. Zude-Sasse, M.; Fountas, S., & Sørensen, C. G., Smart farming technologies for sustainable agriculture: A Review. *Agronomy*., **2020**, *10*(12), 1979.

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Biofertilizers and different organic manures impact on growth and yield of tomato (*Solanum lycopersicum* L.) cv. Bhagya

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ABSTRACT

The current investigation was carried out at the main experimental station, Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi (U.P). Impact of biofertilizers and different organic manures on growth and yield of tomato (*Solanum lycopersicum* L.) cv. Bhagya during rabi season of the year 2023-24. A Block Design that was Randomized used in the trial, and seven treatment combinations were possible *viz.*, T1 (FYM 20 t/ha + PSB 1.5 kg/ha), T2 (Azo 15 kg/ha + FYM 20 t/ha), T3 (Azo 15 kg /ha + PSB 1.5 kg /ha + FYM 20 t/ha), T4 (VC 5 t/ha+ FYM10 t/ha), T5 (Azo 10 kg/ha + PSB 1.5 kg/ha + VC 10 t/ha), T6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) and T_7(Control (RDF 100%) and Three duplicates of each treatment were conducted. Analysis of the data showed that, under the specific agro-climatic conditions of the area, the effects of bio-fertilizers and other organic manures on key metrics such as tomato yield, and vegetative development were highly influenced. In terms of several vegetative growth and yield the treatment (T6) had a substantial impact on plant height (58.46 cm 90DAT), Number of branches/ plant (12.00 90DAT), Leaf area index (38.62 cm^2), Days to 50% flowering (63.2), Number of clusters/branch (4.29), Number of flowers /cluster(11.10), Fruit weight (44.25 g), Number of fruit/plant (21.37), Yield (348.14 quintal/hectare). While, the lowest yield (285.18 quintal/hectare) were noted in Control (T7 RDF 100%).

Key words: *Tomato, Growth, Biofertilizers and Organic manures*

Introduction

Tomato (*Lycopersicum esculentum* L.) is a dicotyledonous self--pollinating annual herb. It is the second most important vegetable crop globally, following by potato. It belongs to the Solanaceae family and has a diploid chromosome number of 24 and grown in both temperate and tropical regions worldwide. Currently, agriculture heavily depends on chemical fertilizers, pesticides, and growth regulators to enhance crop yields. This reliance has sparked a need to explore alternatives to chemical-based farming, a trend that is gradually gaining traction in the Western world. The excessive use of agrochemicals, including fertilizers, has been shown to cause numerous environmental issues. Narayan (2011) describe organic farming as a method that either completely avoids or significantly reduces the use of synthetic fertilizers, pesticides, growth regulators, and livestock feed additives. Solanaceous vegetables typi-

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cally need substantial amounts of primary nutrients like nitrogen, phosphorus, and potassium, as well as secondary nutrients such as calcium and sulfur, to achieve optimal growth, quality, and yield. The rising costs of inorganic fertilizers have made them increasingly unaffordable for small and marginal farmers. Applying expensive inputs to crops with marginal returns has become impractical. In this context, using biofertilizers presents a cost-effective alternative. Phosphorus-solubilizers are biofertilizers that make phosphorus in the soil more accessible to plants. Azospirillum, a heterotrophic nitrogen-fixing organism, has been shown to be beneficial and economical for various crops, enhancing growth, yield, and productivity (Okon, 1985). While the use of chemical fertilizers cannot be completely avoided, their consumption can be reduced by incorporating alternative fertilization sources such as organic manure and biofertilizers.

Materials and Methods

The present study was carried out at the main experimental station, Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi (U.P). The experiments were laid out in completely randomized design and seven treatment combinations were possible viz., T1 (20 t/ha FYM + 1.5 kg PSB), T2(15 kg Azotobacter + 20 t/ha FYM), T3 (15 kg Azotobacter + 1.5 kg PSB + 20 t/ha FYM), T4(Vermicompost 5 t/ha + 10 t/ha FYM), T5(10 kg Azotobacter + 1.5 kg PSB + 10 t/ha Vermicompost), T6(7.5 kg Azotobacter + 1.5 kg PSB + 2.5 t/ha Vermicompost + 10 t/ha FYM) and T7(Control (RDF 100%) with three replications. The observations were recorded i.e. Plant height (cm), Number of branch (cm), Leaf area index (cm^2), Days to 50% flowering, Number of clusters/branch at 60 DAP, Number of flowers/ clusters, Fruit weight (g), Number of fruit/plant. In this experiment 120:60:60 RDF (Control) were used to fertilize the area.

Results and Discussion

From the statistical data (Table 1) data it is revealed that T_6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) had highest plant height at 30 DAT (29.41 cm), 60 DAT (44.27 cm) and at 90 DAT (58.46 cm) in compare to other treatment combinations. Whereas, Minimum height of plant was observed in T_7 (RDF100%) at 30 DAT (23.21 cm), 60 DAT (39.86 cm) and at 90 DAT (50.22 cm). A balanced nutrient supply plays a vital role to ensure, enhance nitrogen uptake and it help to encourage, synergistic microbial activity that leads to stimulate, targeted nutrient release occurs, and specific plant growth promoting effects are provided. The results of the present investigation are in corroboration with the findings of Sajindranath *et al*. (2002). Increased growth might be due to better mobilization of various essential nutrient and water. RDF + Azotobacter + PSB+ Vermicompost +FYM is a more promising method for achieving ideal plant height in tomato cultivation because these elements work together to impart plant growth and height. Maximum number of braches on each plant recorded from T_6 (7 Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) at 90 DAT (12.00) and followed

Table 1.

Tr. No.	Treatments	Plant height (cm)			Number of branch/Plant			Leaf area index (cm^2)
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	
T_1	FYM 20 t/ha + PSB 1.5 kg/ha	24.32	39.86	50.85	5.25	7.44	9.25	32.15
T_2	Azo 15 kg/ha + FYM 20 t/ha	24.40	40.29	52.75	5.27	7.55	10.65	34.25
T_3	Azo 15 kg /ha + PSB 1.5 kg /ha + FYM 20 t/ha	24.44	41.21	53.00	6.22	8.75	11.17	35.82
T_4	VC 5 t/ha+ FYM10 t/ha	25.25	42.21	56.75	6.32	9.25	11.29	37.50
T_5	Azo 10 kg/ha + PSB 1.5 kg/ha + VC 10 t/ha	27.42	42.29	57.00	7.12	9.78	11.59	38.59
T_6	Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha	29.41	44.27	58.46	7.95	11.25	12.00	38.62
T_7	Control (RDF100%)	23.21	39.86	50.22	4.86	7.27	8.55	30.56
	S.Em	**0.04**	**0.07**	**0.80**	**0.12**	**0.11**	**0.19**	**0.59**
	CD (P = 0.05)	1.30	2.06	2.47	0.36	0.33	0.59	1.82

Azotobacter-Azo,Vermicompost-Vermi

Table 2.

Tr. No.	Treatments	Days to 50% flowering	Number of clusters/ branch	Number of flowers/ clusters	Fruit weight (g)	Number of fruit/ plant	Yield/ ha
T_1	FYM 20 t/ha + PSB 1.5 kg/ha	59.0	2.58	8.75	41.01	19.89	302.11
T_2	Azo 15 kg/ha + FYM 20 t/ha	61.7	2.69	9.11	42.12	20.16	314.50
T_3	Azo 15 kg /ha + PSB 1.5 kg /ha + FYM 20 t/ha	62.6	2.88	9.25	43.04	20.64	329.02
T_4	VC 5 t/ha+ FYM10 t/ha	62.8	3.05	10.65	43.64	20.88	337.48
T_5	Azo 10 kg/ha + PSB 1.5 kg/ha + VC 10 t/ha	63.0	3.89	10.75	43.92	21.02	341.92
T_6	Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha	63.2	4.29	11.10	44.25	21.37	350.23
T_7	Control (RDF100%)	58.3	2.52	7.86	40.56	19.21	288.58
	SEm	0.81	0.05	0.16	0.90	0.20	6.43
	CD (P = 0.05)	2.49	0.17	0.48	2.78	0. 63	19.80

Azo-Azotobacter, VC-Vermicompost-, FYM- Farm Yard Manure, PSB- Phosphate solubilizing bacteria

by T_5 (10 kg Azo+ 1.5 kg PSB+10 t/ha Vermi) at 90 DAT (11.59) While, minimum number of branches were recorded from T_7 (RDF100%) at 90 DAT (8.55). Similar results were also obtained by Sharma (1995) and Joshi *et al*. (2015). The best treatment was T_6 which recorded maximum leaf (38.62 cm^2). This was closely followed by T_5 having (Azo 10 kg/ha + PSB 1.5 kg/ha + VC 10 t/ha) (38.59 cm^2). T_4 having (VC 5 t/ha+ FYM10 t/ha, 37.50 cm^2) and then T_3 having (35.82 cm^2). While, the lowest leaf area only 30.56 cm^2 was obtained under the control treatment.

Table 2 data revealed that emergence of 50% flowering was influenced significantly due to apply various combination of treatment. The treatment T_6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) a took maximum period (63.2 days) to reach upto 50% flowering. This was followed by the treatments like T_3, T_4, and T_5 which have taken the equal period to reach up to 50% flowering (62.8 to 63.0 days). On the other hand, the minimum period (58.3 days) was taken to reach upto 50% flowering in case of control (T_7) treatment. The mean data are exhibited in Table 2 revealed that the maximum no. of cluster per/branch (4.29) With T_6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha). Whereas, minimum number of cluster per/branch 2.52 was noted in T_7. Appropriate amount of nutrient supply might increases the formation of flower cluster. PSB+Vermicompost+Azotobacter support robust flower production, ultimately contributing to increased fruiting potential and higher overall yield in tomato. The average flowers/ cluster are presented in Table 2. Among all treatment T6 had maximum number of the flowers/ cluster (11.10) followed by T_5 (10.75/cluster). Whereas the significantly minimum number of flowers (7.86/cluster) was obtained from the control (T_7) treatment. The maximum fruit weight (44.25g) was noted with treatment T6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) While, minimum was noted (40.56g) in T_7 (control). The results of the present investigation are in corroboration with the findings of Kumar *et al.*, 2010, Kumar *et al*. 2018 and Bai *et al* (2024). The maximum number of fruit per plant was observed in T_6 followed by T_5 and this was closely followed by T_4, T_3 and T_2 whereas, the minimum number of fruit per plant was observed in T_7. The combined application of Azotobacter+ PSB+ Vermicompost+ FYM enhanced the vegetative and reproductive growth by improving the soil fertility, providing additional organic matter and essential nutrient which boosts plant biomass. Maximum yield per hectare (350.23 q/ ha) was recorded in T_6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha). While, minimum yield per hectare (350.23 q/ ha) was recorded in T_7 Control (RDF100%). This might be happen due to synergetic inputs of these treatments. Similar results were also obtained by Kanaujia *et al*. (2012); Manickam *et al*. (2021); Bai *et al* (2024).

Conclusion

This study suggests that bio-fertilizers and organic manures improve morphological and yield attributes of tomato. Among all treatments T6 (Azo 7.5 kg /ha + PSB 1.5 kg/ha + VC 2.5 t/ha + FYM 10 t/ha) followed T5(Azo 10 kg/ha + PSB 1.5 kg/ha + VC 10 t/ha) were found superior for all vegetative growth parameters and yield attributes.

Conflict of Interest- None

References

Bai, L., Bundela, M. K., Singh, P., Meena, D.C., Maurya, R.P. and Sharma, A. 2024. Effect of Biofertilizers and Organic Manures on Growth, Yield and Quality of Tomato (*Solanum lycopersicum* L.) *Biological Forum – An International Journal.* 16(1): 136-140.

Joshi, R., Singh, J. and Vig, A.P. 2015. Vermicompost as an effective organic fertilizer and biocontrol agent: effect on growth, yield and quality of plants. *Rev Environ Sci Biotechnol*. 14: 137-159.

Kanaujia, S.P., Singh, V.B. and Singh, A.K. 2012. Effect of integrated nutrient management on growth, yield and quality of tomato. *Journal of Soils and Crops*. 22(1): 65-71.

Kumar, Dharminder, Thakur, K.S., Vikram, Amit, Thkaur, A.K. and Mehta, D.K. 2010. Effect of organic manures and bio-fertilizers on growth and ield of tomato and French bean under mid hills of Himachal Pradesh. *Journal of Hill Agriculture.* 1(2): 176-178.

Kumar, S., Rajeev, S., Singh, V., Singh, M.K. and Singh, Kumar, A. 2018. Effect of plant growth regulators on growth, flowering, yield and quality of tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry*. 7(1): 41-44.

Manickam, S., Suganthy, M. and Ganesh, R. 2021. Influence of different nutrient management practices on growth, yield, quality and economics of brinjal (*Solanum melongena* L.). *Madras Agricultural Journal*. 108 spl. 1-6

Narayana, S. 2011. Organic farming in India: Relevance, problems and constraints. *Financing Agric.* 43(4): 16-22.

Okon, Y. 1985. Azospirillum as a potential inoculant for agriculture. *Trends Biotechnol*. 3(9): 223-228.

Sajindranath, A.K., Narwadkar, P.R., Prabu, T. and Rathod, N.G. 2002. Effect of biofertilizers and growth regulators on germination in okra. *South Indian Horticulture*. 50(4-6): 538-542.

Sharma, Neerajkant, 1995. *Comparative study on the effect of biofertilizers, compost and chemical fertilizers on the growth, yield and quality of okra.* M.Sc. (Ag.) Thesis, JNKVV, Jabalpur.

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Comparative evaluation of growth and yield in improved and local Radish varieties in Varanasi region

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Abstract
An investigation was conducted to assess the performance of various radish varieties, focusing on growth, yield, and quality attributes. Statistical analysis of the data revealed significant varietal differences across all parameters. For growth, Kashi Mooli-40 demonstrated the highest leaf count (10.73), while Pusa Desi exhibited the greatest shoot length (6.73 cm). The shoot length was maximum (6.73 cm) in Pusa Desi. The variety Kashi Lohit has recorded maximum (1223.87 cm^2) leaf area. The variety Kashi Hans required minimum (43.33) number of days for the edible size of root. The significant differences in yield parameters were observed. The root weight and shoot weight was maximum in variety Kashi Hans and Pusa Himani had the highest root-to-shoot ratio (4.45). Ultimately, Pusa Reshmi was identified as the superior variety for yield, producing the maximum root yield of 33.23 kg per plot.

Keywords: *Raphanus sativus*, radish, varietal evaluation, yield, quality, Varanasi

Introduction
Radish (*Raphanus sativus L.*) is a globally cultivated root vegetable with a history of human consumption dating back to at least 400 BC. It was recorded for human consumption dates back to approximately 400 BC, indicating that it is an ancient domesticated species native to both the Eastern Mediterranean and Eastern Asia (Becker 1962; George and Evans 1981; Kaneks and Matsuzawa 1993) [3, 10, 11]. The Middle East and Eastern Asia are considered its centers of origin. Radish is a diploid, cross-pollinated brassicaceous crop with 2n=18 chromosomes. Varieties can be annual or biennial and are grown for their swollen tap roots, which can be globular, tapering, or cylindrical. It is a diploid organism possessing two sets of eighteen chromosomes (2n=18), (Richharia 1937) [18]. The ideal temperature for achieving optimal size, texture, and enhanced flavor ranges from 15 °C to 18 °C (Angell and Hillyer, 1962). Radish seeds exhibit superior germination at a temperature of 5 °C, with an optimal threshold of 15 °C to attain the highest germination percentage in radish (Abdel *et al*., 2016) [1].

It is predominantly a cool-season crop (optimum temperature: 15-18 °C), Asiatic varieties are known to tolerate higher temperatures. In India, it is sown from September to January in the northern plains, but can be grown year-round in the milder climate of peninsular India. Radish is a valuable source of vitamin C, minerals, and fiber. The USDA Nutrient Database (2007) notes that 100 g of edible radish contains 94.4 g moisture, 66kJ of energy, and 3.4g carbohydrates. In India, radish cultivation covered 0.212 million hectares in 2019-2020, with an annual production of 3.107 metric tons. This contributes to the national vegetable production, which stood at 191.76 million metric tons from an area of 10.35 million hectares during the same period. The seeds are also a source of fatty oil used for various purposes, including soap making. It is a vital part of agriculture, with India producing 3.107 metric tons of the crop from 0.212 million hectares in 2019-2020.

The crop is a good source of vitamins, minerals, and fiber. Despite its importance and the availability of numerous varieties (such as Pusa Desi, Pusa Chetki, and Kashi Hans), the performance of these cultivars including their growth, yield, and quality varies significantly by location. The increasing demand for salad vegetables highlights the need for varieties that are not only high-yielding but also possess superior quality.

This investigation, therefore, seeks to fill this knowledge gap by assessing the performance of various improved and local radish cultivars specifically in the Varanasi region. Beyond its agricultural significance, radish is also a nutrient-dense food, providing important vitamins, minerals, and fiber. The growing trend of urbanization and changing food habits has led to a sharp increase in the demand for quality salad vegetables. Growers and consumers alike are seeking varieties that not only offer higher yields but also better quality. The new trend in vegetable production is not only to obtain higher yields but also to have better quality produce. Among these factors variety is a predominant. Several varieties of radish are available in the market having varying length, size, colour, taste yield potential and quality parameters.

As radishes constitute a vital component of salads, they remain in high demand throughout the year in metropolitan areas. The growth, yield, and quality of various radish cultivars exhibit considerable variation across different locales and regions. Additionally, certain indigenous varieties have been cultivated for an extended period. Radishes serve as effective companion plants for numerous other crops, likely due to their pungent aroma, which deters a range of insects and pests, including aphids, cucumber beetles, tomato hornworms, squash bugs, and ants. Furthermore, they can act as a trap crop, enticing insect pests away from the primary crops. The performance of a given radish variety is highly dependent on its specific growing environment. Therefore, a localized study is essential to identify the most suitable improved and local cultivars. This investigation was initiated to evaluate and compare the growth, yield, and quality characteristics of different radish varieties under the specific conditions of the Varanasi region. In light of these considerations, the present study is entitled "Comparative Evaluation of Growth and Yield in Improved and Local Radish Varieties in Varanasi region.

Methods and Materials

The experiments were designed using a Randomized Block Design, encompassing three replications and ten treatments, each featuring a single variety. The treatments within each replication were assigned randomly, specifically: T_1 Pusa Desi, T_2 Pusa Chetki, T_3 Pusa Himani, T_4 Pusa Reshmi, T_5 Japanese White, T_6 Kashi Mooli 40, T_7 Kashi Lohit, T_8 Kashi Sweta, T9 Kashi Hans, and T_{10} Kashi Andhra. Seeds from five enhanced radish varieties namely Pusa Deshi, Pusa Chetaki, Pusa Reshami, and Japanese White Radish were procured from diverse sources. Additionally, seeds of five local cultivars, including Kashi Mooli 40, Kashi Lohit, Kashi Sweta, Kashi Hans, and Kashi Aardra, were gathered from farmers within their respective localities as well as from the authantic source in Varanasi.

The land was brought to a fine tilth by ploughing, clod crushing, and two cross harrowing. An area was marked in 30 plots having 2.00×1.75 m2sizes. The distances of 0.5 m was kept between two plots & 1.0 between two replications. Since as per ideal data the requirement of Nitrogen (N), Phosphorus (P) and Potassium (K) per hectare land for radish cultivation is 50 kg, 100 kg and 50 kg respectively. The observations were recorded on the different growth and yield parameter such as Growth (no. of leaves, shoot length, leaf area day required to be edible size), yield (root weight, shoot weight, root shoot ratio, root yield per plot). Test of significance for correlation coefficients at phenotypic level the estimated values were compared with the table value (statistical table by Fisher and Yates, 1963) at (n-1) degree of freedom at 5% level of significance, respectively.

Results and Discussion

Growth performance of different radish varieties

The results of the current investigations revealed that no significant differences were observed regarding the number of leaves, shoot length, leaf area, and the duration required to reach edible size among the various cultivars at distinct growth stages. The apex of leaf count (10.73) was recorded in the Kashi Mooli-40 variety, whereas the nadir (7.20) was noted in the Japanese White cultivar. Maximum shoot length was produced by Pusa Desi (6.73cm). Leaf area per plant was maximum in variety Kashi Lohit (1223.87cm2) and minimum in variety Kashi Aardra (610.24 cm2). The duration required to achieve an edible size ranged from 43.33 to 60.33 days. The minimum duration observed (43.33 days) was recorded for the variety Kashi Hans, whereas the maximum (60.33 days) was necessitated by the variety Pusa Himani. This might be due to the genetic makeup of the plant and its expression to the growing soil and environmental conditions. Similar result were found by Ponnuswami *et al.* (1980) [14], Rabbani *et al.* (1998) [16] and Pujari *et al*. (1977) [15] in radish.

Yield and quality characters of different radish varieties

The results indicated that the root weight, shoot weight, root-to-shoot ratio, and root yield were significantly influenced across the various cultivars. Data pertaining to root weight revealed that the maximum was observed in the Kashi Hans variety (160.46 g). However, the minimum root weight (132.53 g) was recorded in variety Pusa Reshmi. The maximum shoot weight (64.85 g) was observed in variety Kashi Hans and the minimum (29.98g) in Pusa Himani. The maximum root: shoot ratio was obtained (4.45) in Pusa Himani and minimum (2.34) in Kashi Lohit. The maximum root yield, recorded at an impressive 33.23 kg per plot, was achieved by the variety Pusa Reshmi, whereas the minimum yield of 24.16 kg per plot was observed in the variety Kashi Aardra. The disparities in maturity periods can be ascribed to the inherent genetic differences among the cultivars, along with the ecological and climatic conditions influencing their growth. The variation in the root weight, shoot weight, root: shoot ratio and root yield might be due to genetic variation changes in climatic conditions and Management factors. Similar trend of result was also observed by Rajagopal *et al.* (1979) [17], Dixit *et al.* (1980) [9], Deotale *et al.* (1994) [7].

Table 1: Varietal performance in the growth stages of radish (*Raphanus sativus* L.)

Treatment	No of leaf /plant			Shoot length (cm)			Leaf area/ plant (cm2)			Day require to be edible size
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	
T_1 Pusa Desi	3.15	6.26	8.23	2.76	4.91	6.73	35.22	424.43	937.75	55.00
T_2 Pusa Chetaki	3.32	7.37	9.68	2.12	3.78	5.50	27.00	452.20	733.43	45.67
T_3 Pusa Himani	2.80	5.00	9.22	2.30	4.20	6.46	28.27	525.22	1113.04	60.33
T_4 Pusa Pusa Reshmi	3.30	6.87	8.90	2.87	4.32	6.48	22.40	510.20	1010.31	60.33
T_5 Japanese White	4.21	5.32	7.20	2.63	4.90	6.23	30.24	412.21	932.28	45.00
T_6 Kashi Mooli-40	3.72	6.52	10.73	2.83	3.95	5.72	24.52	352.21	915.51	51.00
T_7 Kashi Lohit	2.92	5.47	9.40	2.42	4.30	6.32	31.17	623.48	1223.87	47.67
T_8 Kashi Sweta	3.46	7.25	10.00	2.67	4.37	6.20	25.03	342.52	670.15	48.33
T9 Kashi Hans	4.33	8/21	10.39	2.42	3.70	5.93	30.48	357.44	660.22	43.33
T_{10} Kashi Aardra	3.40	6.84	9.24	2.50	2.77	6.12	26.32	180.33	610.24	46.00
SEDm	0.182	0.302	0.840	0.183	0.278	0.314	0.452	2.374	8.729	2.183
CD at 5%	0.383	0.635	1.764	0.384	0.584	0.660	0.951	4.988	18.339	4.587

Table 2: Varietal performance in relation to yield parameters in the radish (*Raphanus sativus* L.) crop

Treatment	Root weight (g)	Shoot weight (g)	Root Shoot ratio	Root yield (kg/plot)
T_1 Pusa Desi	132.82	46.97	2.83	26.30
T_2 Pusa Chetki	137.86	52.16	2.64	30.42
T_3 Pusa Himani	133.29	29.98	4.45	28.68
T_4 Pusa Reshmi	132.53	39.45	3.36	33.23
T_5 Japanese white	150.41	59.81	2.52	26.80
T_6 Kashi Mooli-40	147.62	60.75	2.43	31.65
T_7 Kashi Lohit	141.15	60.32	2.34	28.47
T_8 Kashi Sweta	155.45	58.02	2.68	24.30
T_9 Kashi Hans	160.46	64.85	2.47	29.89
T_{10} Kashi Aardra	140.81	49.86	2.82	24.16
SEDm	2.109	0.473	0.080	0.331
CD at 5%	1.922	0.944	0.167	0.696

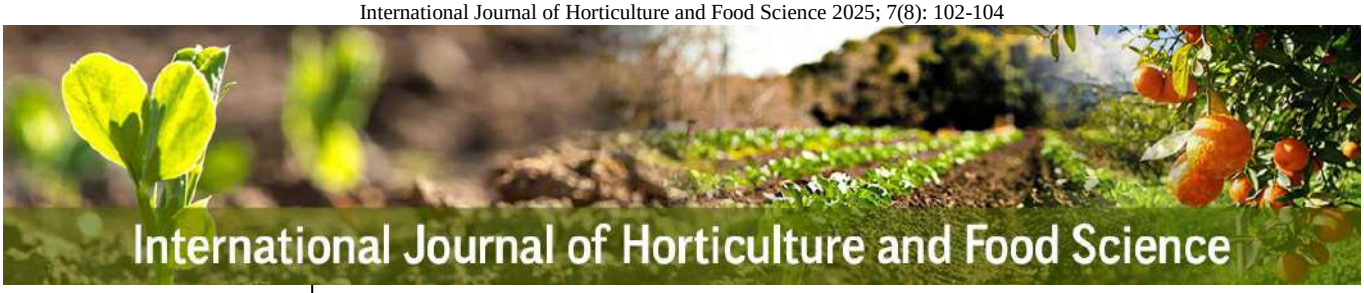
Conclusion

The critical evaluation of the outcomes of the present investigation revealed that significant variations were observed in the growth and yield of the various radish cultivars examined. A positive correlation was identified between root yield and several growth and root characteristics, including shoot length, leaf area, edible size, and root girth. In summary, the radish varieties Pusa Desi, Kashi Hans, Pusa Reshmi, Pusa Himani, Japanese White, Kashi Mooli-40, and Kashi Sweta demonstrated markedly superior performance concerning most growth, yield, and quality parameters. Consequently, these varieties are well-suited to the agro-climatic conditions of Varanasi. Among the local cultivars, the variety Kashi Mooli-40 yielded the most favorable results.

References

1. Abdel CG, Asaad SS, Mohammad DS. Minimum, optimum and maximum temperatures required for germination of onion, radish, tomato and pepper. Int J Farming Allied Sci. 2016;5(1):26-45.
2. Angell FF, Hillyer IG. Cultural and environmental conditions affecting radish root hypocotyls development. Proc Am Soc Hortic Sci. 1962;81:402-407.
3. Becker G. Handbuch Die Kulturpflanze. Vol. 6. Stuttgart; 1962, p. 23-78.
4. Bose TK, Kabir J, Das P, Joy PP. Tropical Horticulture. Vol. 1. Calcutta: Naya Prakash; 2000, p. 145.
5. Bhatti MH, Ullah HI, Khan S, Shakoor A. Studies on evaluation of exotic and local cultivars of radish. Pak J Agric Res. 1983;4(1):17-21.
6. Chapagain TR, Piya S, Dangal NB, Mandal JL, Chaudhary BP. Comparisons of commercial and local cultivars of radish at different levels of manures and fertilizers. Nepal J Sci. Technol. 2010;11:51-56.
7. Deotale AB, Bilorkar PV, Bedvaik NG, Patil SR, Rathod JR. Studies on performance of some radish (*Raphanus sativus* L.) cultivars under Nagpur conditions. J Soils Crops. 1994;4(2):120-121.
8. Dhananjaya. Organic studies in radish (*Raphanus sativus* L.) varieties [MSc Thesis]. Dharwad: University of Agricultural Sciences; 2007, p. 63.
9. Dixit J, Singh RP, Gaur GS. A note on varietal performance of radish (*Raphanus sativus* L.). Haryana J Hortic Sci. 1980;9(1-2):98-100.
10. George R, Evans D. A classification of winter radish cultivars. Euphytica. 1981;30:483-492.
11. Kaneko Y, Matsuzawa Y. Radish (*Raphanus sativus* L.). In: Bassett MJ, editor. Genetic Improvement of Vegetable Crops. Oxford: Pergamon Press; 1983, p. 487-505.
12. Kumar JC, Sooch BS, Khurana BS. Evaluation of radish cultivars for yield and its parameters during spring season. Punjab Veg Grower. 1995;(30):62-63.
13. Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD). Philippine recommends for radish. Los Baños: PCARRD; 2009. Available from: http://mboard.pcarrd.dost.gov.ph/forum.viewtopic.php/id-11385
14. Ponnuswami V, Vadives E. Studies on variability in radish (*Raphanus sativus* L.). South Indian Hortic. 1980;30:42-44.
15. Pujari MM, Jain MM, Mishra GM. Investigation on morphological features and yield potential of promising radish (*Raphanus sativus* L.) cultivars. Haryana J Hortic Sci. 1977;6(1-2):85-89.

16. Rabbani MA, Murakami Y, Kuginuki Y, Takayanagi K. Genetic variation in radish (*Raphanus sativus* L.) germplasm from Pakistan using morphological traits and RAPDs. Genet Resour Crop Evol. 1998;45:307-316.
17. Rajagopal A, Rangaswamy P, Metha A. Studies on varietal evaluation in radish. South Indian Hortic. 1979;27:75-78.
18. Richharia RH. Cytological investigation of *Raphanus sativus*, Brassica oleracea and their F1 and F2 hybrids. J Genet. 1937;1:19-44.
19. Salaria AS, Salaria BS. Horticulture at a Glance. Vol. 2. New Delhi: Jain Brothers; 2009, p. 7-8.
20. Singh GP, Pandita ML, Singh GR. Effect of date of sowing on growth, yield and quality of different cultivars of radish. Haryana J Hortic Sci. 1979;8(3-4):134-138.
21. US Department of Agriculture. USDA table of nutrient retention factors, release six. Nutrient Data Laboratory [Internet]. Washington (DC): USDA; 2007 [cited 2025 Aug 22]. Available from: http://www.ars.usda.gov/main/docs.htm?docid=9448
22. Warwick S. Brassicaceae in agriculture. In: Schmidt R, Bancroft I, editors. Genetics and Genomics of the Brassicaceae. Gatersleben: Springer; 2011, p. 33-66.



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The effect of micronutrients and GA_3 on growth and yield of tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan

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Abstract
This study was conducted with the objective to determine the effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan and an experiment was conducted at the horticultural farm, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized block design (RBD) with seven treatments replicated three times comprising GA_3 and micronutrients with control i.e. T_1: GA_3 (50ppm), T_2: GA_3 (100ppm), T_3: $ZnSO_4$ (0.5%), T_4: $ZnSO_4$ (1%), T_5: Boric acid (50ppm), T_6: Boric acid (100ppm) and T_7: Control. Significantly, differences were found for plant growth parameters *viz*. plant height (cm), number of branches plant^{-1}, number of flower cluster^{-1}, number of cluster plant^{-1}, was recorded highest in T_2: GA_3 (100ppm). The treatment T_2: GA_3 (100ppm) was also found best in early days to 50% flowering, days to first fruit set and yield attributes *viz*., no. of fruit per cluster, no. of fruit plant^{-1}, average fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg) and fruit yield (q/ha) in tomato cv. Kashi Chayan. It is revealed that the use of GA_3 at the concentration of 100ppm, considerably increased the vegetative growth parameters and significantly increased growth and yield of tomato.

Keywords: Micronutrients, GA_3, Growth and Yield

Introduction
Tomato (*Lycopersicon esculentum* Mill.) is a member of the Solanaceae family and is a diploid species with a chromosome number of 2n=24. Originally native to Peru and Mexico, it is now widely cultivated across the globe due to its ability to thrive in a variety of soil types and climates (Gerszberg *et al.*, 2015) [4]. The top tomato-producing countries include China, the United States, India, Egypt, Turkey, Iran, Mexico, Brazil, and Indonesia [FAO, 2022]. Tomato is a warm-season crop that is sensitive to cold temperatures (Afshari *et al*., 2014) [1]. It can be cultivated in both the wet and dry seasons, provided the annual rainfall ranges from 60 to 150 cm. However, excessive rainfall during its growth period can be detrimental to the plant. Micronutrients play a crucial role in plant processes, and foliar application of these nutrients can enhance both the quality and yield of tomatoes (Ali *et al*., 2012) [2] by boosting the photosynthetic activity in green plants (Singh and Tiwari, 2013) [13]. Micronutrients management is essential to boost the crop production and also increased the fruits quality. Boron and zinc important micronutrient for quality tomato fruit production. Zinc regulates growth and also promotes balanced sugar consumption and Boron helps to providing some nutrients and essential for proper development of their fruits and seeds. Gibberellic acid is a key growth regulator with various potential applications for altering plant growth, yield, and yield-related traits (Rafeekher). Considering the facts, the current study aims to examine the effects of Micronutrients and GA_3 on the growth and yield of tomato.

Materials and Methods
A field experiment entitled " The effect of micronutrients and GA_3 on growth and yield of Tomato (*Lycopersicon esculentum* Mill.) cv. Kashi Chayan" was conducted at the experimental field of Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi (U.P.) during Rabi season of 2023-2024. Experiment was laid out in a randomized

block design (RBD) with seven treatments replicated three times comprising GA_3 and micronutrients with control i.e. T_1: GA_3 (50ppm), T_2: GA_3 (100ppm), T_3: $ZnSO_4$ (0.5%), T_4: $ZnSO_4$ (1%), T_5: Boric acid (50ppm), T_6: Boric acid (100ppm) and T_7: Control. The collected data includes plant height (cm), number of branches plant^{-1}, number of flower cluster^{-1}, number of cluster plant^{-1}, early days to 50% flowering, days to first fruit set and yield attributes *viz*., no. of fruit per cluster, no. of fruit plant^{-1}, average fruit weight (g), fruit length (cm), fruit width (cm), fruit yield per plant (kg) and fruit yield (q/ha) in tomato cv. Kashi Chayan. The data was analyzed using analysis of variance (ANOVA), and mean separation was performed at a 5% probability level.

Results and Discussion

The data on the effects of various micronutrients and GA_3 on plant height at different growth stages were statistically analyzed and are detailed in Table 1. It clearly showed that the plant height differed significantly with each other, the maximum plant height (118.23 cm) was recorded in the treatment T_2 (GA_3 @ 100 ppm. The minimum plant height was noted 92.40 cm at the time of harvesting in treatment T_7 (Control). The data on the effects of various micronutrients and GA_3 on no. of branches per plant at different growth stages were statistically analyzed and are detailed in Table 1. It clearly showed that the no. of branches differed significantly with each other, the highest no. of branches (11.95) was recorded in the treatment T_2 (GA_3 @ 100 ppm). The lowest no. of branches was noted 7.10 at the time of harvesting in treatment T_7 (Control).

The shortest duration to reach 50% flowering in tomato plants was observed in treatment T_2 (GA_3 @ 100 ppm), requiring just 62.34 days. This was followed by treatment T_1 (GA_3 @ 50 ppm), which required 64.29 days. In contrast, the longest duration of 76.51 days to reach 50% flowering was recorded in the control treatment T_7. Onofeghara (1981) [8] reported similar findings, attributing them to the role of GA_3 in regulating flower initiation and development. GA_3 is crucial for both male and female fertility (Griffiths *et al.*, 2006) [5]. The data on the effects of various micronutrients and GA_3 on no. of flower per cluster were statistically analyzed and are detailed in Table 1. The highest number of flowers per cluster, averaging 6.86, was observed in treatment T_2 (GA_3 @ 100 ppm). This was followed by T_1 (GA_3 @ 50 ppm) and T_6 (Boric acid @ 100 ppm), which had 6.47 and 5.38 flowers per cluster, respectively. The highest number of clusters per plant, at 5.86, was observed in treatment T_2 (GA_3 @ 100 ppm), followed by T_1 (GA_3 @ 50 ppm). Both micronutrients and GA_3 had a notable impact on the days to the first fruit set during the 2023-24 period. The shortest duration to the first fruit set, at 72.77 days, was observed in treatment T_2 (GA_3 @100 ppm), followed by T_1 (GA_3 @ 50 ppm). Both micronutrients and GA_3 had a considerable impact on the timing of the first fruit picking during the 2023-24 period. The shortest time to the first fruit picking, at 87.20 days, was recorded in treatment T_2 (GA_3 @100 ppm), followed by T_1 (GA_3 @50 ppm) at 88.35 days.

The data on the effects of various micronutrients and GA_3 on no. of fruits per plant were statistically analyzed and are detailed in Table 2. Among the treatments, T_2 (GA_3 @ 100 ppm) yielded the highest number of fruits per plant at 47.80, showing a significant improvement compared to other treatments. This was followed by T_1 (GA_3 @ 50 ppm), which produced 44.60 fruits per plant. In contrast, the control (T_7) recorded a significantly lower number of fruits per plant (22.43).

The longest fruit length, measuring 6.10 cm, was observed in treatment T_2 (GA_3 @ 100ppm), which was significantly superior to other treatments. This was followed by T_1 (GA_3 @ 50 ppm) and T_4 ($ZnSO_4$ @ 1%), with fruit lengths of 5.98 cm and 5.05 cm, respectively. The shortest fruit length, at 3.57 cm, was recorded in the control group T_7. The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. The greatest fruit width, measuring 5.14 cm, was observed in treatment T_2 (GA_3 at 100 ppm), followed by T_1 (GA_3 at 50 ppm) at 4.98 cm. The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. The weight of individual tomato fruits varied significantly with the application of different levels of GA_3 and micronutrient. The highest average fruit weight (104.46g), was recorded in treatment T_2 (GA_3 @ 100 ppm), followed by T_1 (101.73g) and T_4 (98.40g). The lowest average fruit weight, 82.32g, was observed in the control (T_7). These findings are reported by Lilov and Donchev (1984) [7] Naeem *et al.* (2001) [9].

The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. Statistical analysis of the data on tomato fruit yield per plant (Kg) revealed significant differences. Different levels of GA_3 had a significant impact on the yield of fruit per plant. The highest yield, at 3.33 kg per plant, was achieved with 100 ppm GA_3, while the lowest yield, 1.56 kg per plant, was observed under control conditions.The results of various levels of micronutrients and GA_3 across different treatment combinations are shown in Table 2. Statistical analysis of the data on tomato fruit yield per hectare (q) revealed significant differences. The application of different levels of GA_3 significantly affected the fruit yield per hectare. The highest yield, 437.35 q/ha, was obtained with T_2 (GA_3 @ 100 ppm), followed by T_1 (GA_3 @ 50 ppm) at 407.87 q/ha whereas the lowest yield, 240.56 q/ha, was recorded in the control (T_7).

Conclusion

The results of the present study indicate that the application of GA_3 (50 ppm and 100 ppm) and micronutrients such as $ZnSO_4$ (0.5% and 1%) and boric acid (50 ppm and 100 ppm) notably enhanced vegetative growth, flowering, and significantly boosted tomato yield. Based on these findings, it can be concluded that GA_3 at a concentration of 100 ppm was the most effective treatment for improving both vegetative growth and yield in tomato variety Kashi Chayan.

Table 1: Effect of micronutrients and GA_3 on plant height, no. of branches, days to 50% flowering, no. of flower per cluster, no. of cluster per plant, days to first fruit set and days to first fruit picking

Tr. No.	Treatment details	Plant height (cm)	No. of branches	Days to 50% flowering	No. of flower per cluster	No. of cluster per plant	Days to first fruit set	Days to first fruit picking
T_1	GA_3 (50ppm)	115.75	11.03	64.29	6.47	4.37	73.51	88.35
T_2	GA_3 (100ppm)	118.23	11.95	62.34	6.86	5.86	72.77	87.20
T_3	$ZnSO_4$ (0.5%)	107.47	10.25	72.31	5.12	3.98	77.15	91.92
T_4	$ZnSO_4$ (1%)	109.32	10.98	71.03	5.26	4.32	76.87	89.99
T_5	Boric Acid (50ppm)	110.87	9.33	68.01	5.28	4.28	77.67	92.85
T_6	Boric Acid (100ppm)	112.17	9.98	67.20	5.38	4.08	76.37	90.98
T_7	Control	92.40	7.10	76.51	4.24	3.24	80.11	94.01
SEm±		1.95	0.13	1.44	0.05	0.04	1.45	1.36
CD at 5%		6.02	0.41	4.44	0.17	0.13	4.47	4.19

Table 2: Effect of Micronutrients and GA_3 on no. of fruits per plants, fruit length (cm), fruit width (cm), fruit weight (g), fruit yield (kg/plant) and fruit yield (q/ha)

Tr. No.	Treatment details	No. of fruits per plant	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Fruit yield (Kg/plant)	Fruit yield (q/ha)
T_1	GA_3 (50ppm)	44.60	5.98	4.98	101.73	3.27	407.87
T_2	GA_3 (100ppm)	47.80	6.10	5.14	104.46	3.33	437.35
T_3	$ZnSO_4$ (0.5%)	37.47	4.93	4.18	97.07	2.89	304.76
T_4	$ZnSO_4$ (1%)	39.38	5.05	4.25	98.40	2.93	321.02
T_5	Boric Acid (50ppm)	34.06	4.79	4.04	91.29	2.31	337.10
T_6	Boric Acid (100ppm)	35.99	4.86	4.13	95.30	2.64	353.20
T_7	Control	22.43	3.57	3.57	82.32	1.56	240.56
SEm±		0.71	0.07	0.07	1.01	0.03	6.43
CD at 5%		2.18	0.22	0.20	3.11	0.09	19.81

References

1. Afshari M, Afsharmanesh GHR, Yousef K. The effect of enriched organic fertilizer and methanol spray on the greenhouse-tomato yield. J Agric Sci. 2014;6(11):14-20.
2. Ali S, Javed HU, Rehman RN, Sabir IA, Naeem MS, Siddiqui MZ, Saeed DA, Nawaz MA. Foliar application of some macro and micronutrients improves tomato growth, flowering and yield. Int J Biosci. 2012;3(10):280-7.
3. Food and Agriculture Organization of the United Nations. World food and agriculture - statistical year book 2022. Rome: FAO; 2022: https://openknowledge.fao.org
4. Gerszberg A, Konka KH, Kowalczyk T, Kononowicz AK. Tomato (*Solanum lycopersicum* L.) in the service of biotechnology. J Plant Biotechnol. 2015;120:881-902.
5. Griffiths J, Murase K, Rieu I, Zentella R, Zhang ZL, Powers SJ. Genetic characterization and functional analysis of the GID1 gibberellin receptors in *Arabidopsis*. Plant Cell. 2006;18(3):399-414.
6. Kumar A, Biswas TK, Singh N, Lal EP. Effect of gibberellic acid on growth, quality and yield of tomato (*Lycopersicon esculentum* Mill.). J Agric Vet Sci. 2014;7(4):28-30.
7. Lilov D, Donchev T. Effect of Bulgarian gibberellin preparation on tomato fruiting. Gradinarska Lozarska Nauka. 1984;21(1):49-55.
8. Onofeghara FA. The effects of growth substance on flowering and fruiting of tomato (*Lycopersicon esculentum* Mill.). Phyton (Argentina). 1981;40(1):107-16.
9. Naeem N, Ishitiaq M, Khan P, Mohammad N, Khan J, Jamiher B. Effect of GA3 on growth and yield of tomato cv. Roma. J Biol Sci. 2001;1:448-50.
10. Rafeekar M, Nair SA, Sorte PN, Hatwal GP, Chandan PM. Effect of growth regulator on growth and yield of summer cucumber. J Soils Crops. 2002;12(2):108-10.
11. Ranjeet RB, Ram P, Meena ML. Growth, flowering, fruiting, yield and quality of tomato (*Lycopersicon esculentum* Mill.) as influenced by plant bio-regulators. Int J Plant Sci. 2014;9(1):67-71.
12. Singh HM, Tiwari JK. Impact of micronutrient spray on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.). HortFlora Res Spectrum. 2013;2(1):87-9.