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1

CHAPTER

Enteric Glial Cells: Key Regulators of Gastrointestinal Homeostasis

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Abstract

The enteric nervous system (ENS), often called the "second brain," is a complex, autonomous network governing gastrointestinal (GI) functions. Among its cellular components, Enteric Glial Cells (EGCs) are gaining increasing attention for their multifaceted roles beyond structural support. EGCs, derived from neural crest cells, share morphological and functional features with central nervous system astrocytes and are now recognized as key regulators of neurotransmission, neuroprotection, epithelial barrier integrity, immune responses and gut homeostasis. Their functional diversity includes modulating motility, participating in tripartite synapses, responding to immune cues and even demonstrating neurogenic potential under stress or injury. EGCs interact intimately with neurons, epithelial cells, immune cells and the gut microbiota, serving as central integrators in gut-brain and immune communication. Advances in molecular tools like single-cell RNA sequencing have revealed diverse EGC subtypes, including mechanosensitive "hub cells" critical for motility. In domestic animals, EGCs exhibit conserved roles across species and dysfunctions are linked to diseases such as IBD, colic, parvoviral enteritis and swine dysentery. EGCs express markers like GFAP and S100 β and their modulation through nutraceuticals and probiotics holds therapeutic potential. Glial-derived neurotrophic factors (e.g., GDNF) show promise in promoting mucosal healing and neuronal survival, making EGCs attractive targets for regenerative and anti-inflammatory therapies. Future research should focus on immune profiling, functional subtyping and therapeutic exploitation of EGCs, including glial transplantation and microbiota-mediated modulation. Understanding EGC biology across species paves the way for novel diagnostic tools and precision treatments in gastrointestinal disorders, both in veterinary and human medicine.

1. Introduction

The enteric nervous system (ENS), often referred to as the "second brain," is a sophisticated and intricate network of neurons and supporting cells located within the walls of the gastrointestinal (GI) tract. Among these supportive cells, **Enteric Glial Cells (EGCs)** play a crucial and central role in maintaining the physiological integrity of the ENS with the gastrointestinal environment. These cells are morpho functionally similar to astrocytes of CNS, a key regulators of gut physiology, immunity and homeostasis. Enteric glial cells (EGCs) are now acknowledged as key contributors to neurotransmission, neuroprotection, maintenance of the intestinal barrier and the development of various diseases.

2. Historical Perspective

Although enteric glial cells were initially identified in the early 1900s, their physiological significance was not recognized until the 1990s. The development of molecular markers like S100 β and glial fibrillary acidic protein (GFAP) made it possible to identify and examine EGCs in greater detail. Our knowledge of these cells has significantly increased due to recent developments in imaging, genetics and molecular biology.

3. Origin and Development

3.1. Embryonic Origin

Enteric glial cells are derived from **neural crest cells**, which migrate to the gut during embryogenesis. These versatile progenitor cells differentiate into both enteric neurons and glial cells.

EGCs, like enteric neurons, originate from **neural crest cells (NCCs)**.

- Two primary migratory streams contribute to ENS formation:
 - **Vagal NCCs** (from somites 1–7): colonize the entire GI tract.
 - **Sacral NCCs**: contribute to the distal colon.
- In response to signaling cues (e.g., GDNF/RET, endothelin), NCCs differentiate into neuronal and glial lineages as they colonize the gut.
- Postnatal development: EGCs develop and multiply concurrently with the growth of the gut.
- Adulthood: EGCs can react to inflammation or injury and retain their plasticity.

4. Morphology and Classification

4.1. Morphological Types

EGCs are morphologically heterogeneous and classified based on their location and shape:

3.1 Localization and Morphological Subtypes

Type	Location	Morphological Characteristics
Type I	Intra ganglionic (myenteric/submucosal)	Stellate, astrocyte-like
Type II	Interganglionic fiber tracts	Elongated, fibrous
Type III	Mucosal layer	Small, dense, associated with epithelial crypts
Type IV	Serosa and blood vessels	Flat, perivascular

4.2. Molecular Pathways in Differentiation &Markers

- Sox10: Crucial for starting glial fate and preserving progenitor status.
- Glial differentiation is encouraged over neurogenesis by notch signaling.
- Hes1 and Hes5: Maintain glial identity by inhibiting neuronal genes.
- Neurturin and GDNF: Alter EGC maturation.

EGCs multiply and adjust to physiological changes, including microbial colonization, dietary modifications and mechanical forces, during the postnatal period. In adulthood, they maintain their plasticity and may even function as stem cells in specific circumstances.

The most widely used indicators to detect EGCs are

- Glial Fibrillary Acidic Protein (GFAP): An intermediate filament protein that is triggered during injury and stress.

The calcium-binding protein S100β is used to identify both activated and resting glia.

Glial fate depends on the transcription factor SOX10.

- Mature enteric glial cells (EGCs) express the proteins proteolipid protein 1 (PLP1) and brain lipid-binding protein (BLBP).

Physiological Roles of Enteric Glial Cells

1. Neurotrophic Support

EGCs promote neuronal survival, synaptogenesis and plasticity by

secreting neurotrophin-3 and glial cell line-derived neurotrophic factor (GDNF). Enteric glial cells provide essential structural and functional support to neurons. By expressing precursor molecules, uptake transporters and enzymes that break down neuroactive substances like purines and GABA, glia also control the availability of neurotransmitters. The effects of glial purine degradation enzymes on inflammation and neuron numbers demonstrate how important this regulation is for gut function and neuron survival. By generating glutathione and other related substances, enteric glia offers antioxidant defense, shielding neurons from oxidative damage. Through autocrine signaling, they can modify glutathione synthesis, promoting neuron survival. Furthermore, enteric glia possess latent neurogenic potential: certain glia can develop into neurons in vitro and in vivo under inflammatory conditions, although steady-state neurogenesis is limited. Activating this glial neurogenesis may offer therapeutic opportunities for enteric neuropathies.

2. Synaptic Regulation

- EGCs participate in **tripartite synapses** with enteric neurons:
 - Regulate neurotransmitter uptake (e.g., glutamate via EAATs).
 - Release gliotransmitters (e.g., ATP, NO, prostaglandins).
 - Modulate neuronal excitability via calcium signaling.

3. Roles for Enteric Glia in Enteric Motor Neurocircuits

Through their interactions with myenteric plexus neurons, enteric glia are essential in controlling gastrointestinal motility. Through intercellular signaling, specifically through connexin-43 channels, they affect motor patterns such as peristalsis. While glial impairment slows transit and lessens contractions, glial Ca^{2+} activation increases colonic motility. Glia use neurotransmitters like ATP and acetylcholine to react to particular neural pathways, allowing neural circuits to be precisely modulated. Enzymes such as NTPDase2 break down ATP to preserve balanced purinergic signaling, which controls the levels of extracellular neurotransmitters, particularly purines. Neuroinflammation and disruption of motility can be caused by excessive ATP release during illness.

4. Barrier Integrity and Mucosal Homeostasis

- Influence epithelial tight junctions (e.g., occludin, claudins).
- Regulate mucin production and epithelial turnover.
- Protect the gut lining via anti-apoptotic and regenerative signals.

5. Enteric Glia and Epithelial Functions

Intestinal mucosal enteric glia play a crucial role in maintaining the integrity and homeostasis of the epithelial barrier. Although preliminary ablation research revealed significant epithelial damage, more complex models indicate functional redundancy among glial subtypes, with Plp1+ glia possibly contributing to aging and Gfap+ glia promoting stem cell renewal. By affecting gene expression and secreting substances like GDNF, TGF- β 1 and Wnt ligands, glia improve the function of the epithelial barrier in vitro. Additionally, through interactions with secretomotor neurons, which are partially mediated by connexin-43 signaling, they control epithelial ion transport.

6. Physiological Changes in the Population of Enteric Glial Cells (EGCs)

Age and nutrition are two physiological factors that alter the population of enteric glial cells (EGCs) in the gastrointestinal (GI) tract. With the exception of a slight decrease in the rectum, aging results in a substantial decrease in EGC number and density throughout the majority of the GI tract. EGC populations are also impacted by diet: a high-fat diet causes a significant decrease in myenteric neurons while increasing EGCs in the antrum's myenteric plexus and decreasing EGC density in the duodenal submucosal plexus. On the other hand, despite being neuroprotective for myenteric neurons, food restriction exacerbates glial cell alterations, indicating a complex effect on EGCs. It is still unknown what precise processes underlie these glial changes, whether they are primary or secondary to neuronal degeneration.

7. Immune Interactions

TLRs, NOD-like receptors and cytokine receptors are expressed by EGCs, which allows them to, Identify microbiological components (flagellin, LPS), Generate inflammatory mediators, such as TNF- α , IL-1 β and IL-6 and interact with T-cells, dendritic cells and macrophages.

8. Modulation of Motility

Through modifying excitatory/inhibitory neurotransmitter release, controlling Cajal interstitial cells and influencing slow wave pacing, EGCs indirectly affect smooth muscle activity. Despite being the predominant cell type in the enteric nervous system, the functions of enteric glia remain largely unexplored. Researchers discovered discrete molecular subtypes of enteric glia with varying morphologies and spatial distributions by employing

optimized single nucleus RNA sequencing. One of these, known as "hub cells," is a specific subtype of biosensor. Mice with impaired intestinal motility and delayed gastric emptying were produced by specifically deleting the mechanosensory ion channel PIEZO2 from hub cells, but not from other glial subtypes. Targeting particular glial subtypes may provide novel therapeutic approaches for gastrointestinal disorders, as these findings demonstrate the functional diversity of enteric glia.

9. EGCs and the Gut-Brain Axis

- **Bidirectional Communication:** EGCs respond to CNS inputs and relay peripheral inflammatory or microbial signals back to the brain.
- **Vagal Nerve Interactions:** EGCs may contribute to vagal sensory transduction and neuroimmune reflexes.
- **Stress Responses:** EGC function is modulated by cortisol, CRH and other stress-related hormones.

10. Modulation of Enteric Glial Cells (EGCs) by Nutraceuticals

Enteric glial cells (EGCs), which are essential for immune interactions, gut homeostasis and neuronal support, may be protected or modulated by nutraceuticals with antioxidant, anti-inflammatory, or modulatory qualities. The majority of the evidence, which emphasizes the susceptibility of EGCs to oxidative stress and inflammation as well as the protective function of specific nutraceuticals, comes from animal models of diabetes, aging, inflammation and intestinal injury. The activity of the EGCs was found to be enhanced by antioxidant nutraceuticals such as L-glutamine and glutathione (GSH), plant and fungal extracts (*Trichilia catigua*, *Agaricus blazei* Murril, Brazil Nut, coffee components (caffeic acid & chlorogenic acid), polyphenols: flavonoids and non-flavonoids, resveratrol (non-flavonoid) and probiotics.

11. Probiotics

(*Lactobacillus plantarum*, *Pediococcus acidilactici*, *Bifidobacterium bifidum*) has been found to stabilize the microbiota balance, reducing inflammation and oxidative stress, modulate EGC markers such as GDNF and GFAP, influence EGC-mediated neuroimmune responses and intestinal barrier function. *B. bifidum* inhibits inflammatory processes in EGCs, promoting intestinal homeostasis.

12. Immune Functions of Enteric Glial Cells (EGCs)

- **Metabolic and Structural Support:** In pathological circumstances, EGCs may transdifferentiate into neurons and support enteric

neurons metabolically and structurally, particularly during gut motility.

- **Production of Cytokines and Chemokines:** EGCs are not immune, but they can react to stimuli by producing immune mediators. Microbial products such as LPS can activate them to release IFN- γ , IL-1 β , IL-6, CCL2 and M-CSF. They also express Toll-like receptors (TLRs).
- **Reaction to Immune Signals:** EGCs increase inflammatory signals like IL-6 and IL-18 in response to immune cell cytokines (such as IL-1 β and IFN- γ).

Barrier Maintenance via GDNF and GSNO:

- Glial cell line-derived neurotrophic factor (GDNF), which inhibits epithelial apoptosis and fortifies the integrity of the gut barrier, is primarily produced by EGCs.
- Additionally, GDNF promotes mucosal homeostasis by activating ILC3s to release IL-22.
- To promote the formation of tight junctions, they also release S-nitrosoglutathione (GSNO).
- **Adaptive Immunity and Antigen Presentation:** EGCs can present antigens to CD4⁺ T cells because they express MHC-I and MHC-II.
- They might use immune checkpoint proteins like PD-L1 to suppress CD8⁺ T cell activity.
- Peyer's patches contain EGCs, which may have an impact on B cell immunity.
- Additionally, they express CD200, an immunosuppressive molecule that affects different immune cells.

13. Pro-inflammatory Role of EGCs:

- Detect pathogens via **TLRs**, activate innate immunity.
- Respond to **IL-1 β** and **TNF- α** , enhancing **IL-1 β** and **IL-6** production.
- Present antigens to T cells, sustaining **Th1/Th17** cytokine release.
- **Tissue Repair Functions:**
 - Secrete **GDNF** to activate **ILC3s**, promoting **IL-22** release for epithelial regeneration.

- Release **GSNO** to strengthen epithelial tight junctions.

14. EGCs role in Immunological Gut Disorders

EGCs have been increasingly implicated in gut immune disorders through multiple mechanisms:

- **Pathogen Detection & Innate Immunity:** EGCs are able to detect pathogens through receptors such as TLRs and trigger innate immune reactions.
- **Amplification of Inflammation:** They exacerbate local inflammation in response to immune cells' production of pro-inflammatory cytokines, such as IL-1 β .
- **Adaptive Immune Modulation:** EGCs can affect T cell responses by presenting antigens through MHC molecules.
- **Regulation of the Epithelial Barrier:** EGCs affect gut permeability and homeostasis by interacting with epithelial cells and modifying the integrity of the barrier.

15. Distribution and Function of EGCs in Domestic Animal Species

Comparative Anatomy and Histology

EGCs occur in the myenteric (Auerbach's) and submucosal (Meissner's) plexuses in a variety of veterinary species, including dogs, cats, horses, cattle, pigs, goats and sheep. They share conserved markers like GFAP, S100 β and Sox10 with astrocytes in the central nervous system and their presence throughout the GI tract in all major domestic animals is confirmed by immunohistochemistry and electron microscopy.

Functional Similarities

- In all species, EGCs:
- Provide trophic and metabolic support for enteric neurons.
- Support the function of the intestinal barrier, which is crucial for avoiding systemic infection.
- Control gastrointestinal motility, which is essential for diseases like canine megacolon and equine colic.
- Engage in interactions with immune cells as a component of the network of gut-associated lymphoid tissue (GALT).

16. Veterinary Diseases Involving Enteric Glial Cells

1. EGCs are linked to preserving mucosal integrity in dogs and cats with

inflammatory bowel disease (IBD). Chronic inflammatory cases are characterized by altered expression of GFAP and S100 β . The breakdown of the epithelial barrier may be worsened by glial support loss, which could lead to chronic enteropathy.

2. **Equine Colic and Postoperative Ileus:** EGC activation or damage is associated with inflammatory cytokine levels and impaired motility and disruption of ENS and EGC signaling results in hypomotility or ileus, which is common following colic surgery. Developing pro-motility treatments may be aided by focusing on pathways linked to EGC.
3. **Bovine Johne's Disease** (*Mycobacterium avium* subspecies paratuberculosis): EGC dysfunction may be a contributing factor in the granulomatous inflammation and epithelial damage. The disease's chronicity raises the possibility of glial changes impacting mucosal repair and immune response.
4. **Parvoviral Enteritis in Dogs** Parvovirus leads to massive crypt necrosis and villous atrophy, Secondary damage to **EGCs and the ENS** may impair recovery of GI function post-infection. Glial-derived trophic factors may aid in epithelial regeneration.
5. **Swine Dysentery (*Brachyspira hyodysenteriae*)** EGC-mediated regulation of epithelial integrity is compromised during severe diarrhea. Loss of glial control may contribute to hemorrhagic diarrhea and endotoxemia.

Diagnostic and Research Implications

Biomarkers for GI Health

- GFAP and S100 β levels in tissues or excretions (e.g., feces, serum) could serve as **biomarkers** of enteric health.
- Inflammatory markers derived from EGCs (e.g., IL-6, GDNF) may have predictive value in veterinary gastroenterology.

Therapeutic Potentials in Veterinary Practice

Neurotrophic Factor Therapy

EGC-derived GDNF promotes neuronal health and mucosal healing. Post-operative recovery and chronic enteropathies may benefit from experimental treatments employing GDNF analogs.

EGCs in Regenerative Medicine

- Stem cell-based therapies or **ENS reconstitution** in congenital or

acquired motility disorders may involve EGC transplantation. Potential application in conditions like **canine idiopathic megaesophagus** or **equine aganglionosis**.

Glial Modulation by Probiotics and Nutraceuticals

EGC function may be indirectly improved by nutritional approaches that affect the gut microbiota. Certain probiotics and short-chain fatty acids can boost the expression of GDNF and anti-inflammatory cytokines in EGCs.

Future Perspectives on EGCs – Summary

1. **Comprehensive Immune Profiling:** To fully map the cytokines, chemokines, receptors and antigen-presenting capacities of EGCs and comprehend their full immune potential, more thorough research is required.
2. **Pathological Changes in EGCs:** Investigations should concentrate on the ways in which EGCs alter throughout illnesses, including possible novel subtypes, their reactive states and patterns of cell death or regeneration.
3. **Interaction with Other Systems:** EGCs affect gut immunity and homeostasis through interactions with immune cells, enteric neurons, blood vessels and lymphatics; this complexity necessitates more research.
4. **Therapeutic Targeting:** EGCs show promise as targets for treatments like modifying their antigen presentation to strengthen anti-cancer immunity or increasing GDNF for tissue repair.

Therapeutic Implications

Glial Modulation in Disease

- **GDNF mimetics** and **neurotrophic factor enhancers** to promote healing.
- **Fluorocitrate** to transiently inhibit EGCs (experimental).
- **Anti-inflammatory therapies** targeting reactive gliosis.

Regenerative Medicine

- EGCs as stem/progenitor cell sources for ENS repair.
- **Autologous glial transplantation** being explored in congenital enteric neuropathies.
- **ENS bioengineering** for tissue replacement.

Microbiota and EGC Interaction

- Prebiotics and probiotics modulate EGC function.
- Short-chain fatty acids (e.g., butyrate) enhance GDNF expression and anti-inflammatory responses.

Future Directions

- **Single-cell RNA sequencing** to delineate EGC subtypes and states.
- **Microbiota-glia interactions** as targets for gut-brain disorders.
- **Sex differences** in EGC response to injury and inflammation.
- Integration of EGC biology into **precision medicine** for GI diseases.

Conclusion

Enteric glial cells are central to gastrointestinal health, integrating signals from neurons, epithelial cells, immune components and the microbiota. Their multifunctional roles in homeostasis, inflammation, regeneration and neuroplasticity make them pivotal players in both physiological and pathological processes. Continued research into EGC biology offers promising avenues for developing novel therapies for a wide range of gastrointestinal and neurodegenerative diseases.

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2 CHAPTER

Recent Trends in Musculoskeletal Rehabilitation

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Abstract

Musculoskeletal rehabilitation is undergoing a paradigm shift driven by technological innovation, personalized medicine approaches and evidence-based practice integration. This chapter examines contemporary trends transforming the field, including digital health technologies, artificial intelligence applications, telerehabilitation modalities, precision medicine approaches and advanced assessment techniques. The integration of wearable sensors, virtual reality systems and machine learning algorithms is revolutionizing patient assessment, treatment delivery and outcome monitoring. Telerehabilitation has emerged as a clinically validated alternative to traditional in-person care, particularly following the global health challenges that accelerated digital adoption. Personalized rehabilitation protocols utilizing biomarkers, genomic profiling and individual phenotyping are enabling more targeted interventions. Contemporary evidence demonstrates equivalent or superior outcomes when these innovative approaches are properly implemented, while addressing longstanding barriers including access limitations, cost constraints and geographic disparities. This chapter synthesizes current research, implementation frameworks and future directions for musculoskeletal rehabilitation practice, providing clinicians with evidence-based guidance for incorporating emerging trends into clinical practice.

Keywords: Digital health, telerehabilitation, artificial intelligence, precision medicine, wearable technology, virtual reality, machine learning, biomechanics, patient-centered care, evidence-based practice, movement analysis, remote monitoring

Introduction

Musculoskeletal disorders represent one of the most prevalent and disabling health conditions globally, affecting over 1.7 billion individuals worldwide and accounting for approximately 17% of all years lived with disability^[1]. The economic burden of these conditions continues to escalate, with healthcare expenditures reaching \$61 billion annually in the United States alone^[2]. Traditional rehabilitation approaches, while clinically effective, face significant challenges including limited accessibility, geographic disparities, resource constraints and suboptimal patient engagement^[3].

The landscape of musculoskeletal rehabilitation is experiencing unprecedented transformation driven by technological advancement, evolving healthcare delivery models and growing emphasis on personalized medicine^[4]. Contemporary practice increasingly integrates digital health technologies, artificial intelligence applications and precision medicine approaches to enhance clinical outcomes while addressing systemic barriers to care access^[5]. This evolution represents not merely technological adoption but a fundamental reconceptualization of how rehabilitation services are delivered, monitored and optimized.

Recent evidence demonstrates that innovative rehabilitation modalities can achieve clinical outcomes equivalent to or exceeding traditional approaches while improving accessibility, cost-effectiveness and patient satisfaction^[6]. The COVID-19 pandemic served as a catalyst for rapid adoption of telerehabilitation and digital health solutions, providing real-world validation of their clinical utility and scalability^[7]. Simultaneously, advances in wearable technology, machine learning algorithms and biomarker identification are enabling unprecedented personalization of rehabilitation interventions^[8].

The convergence of these trends is reshaping fundamental aspects of musculoskeletal rehabilitation, from initial assessment and diagnosis through treatment delivery and long-term monitoring. Digital platforms now enable continuous patient engagement, real-time biometric monitoring and data-driven treatment optimization^[9]. Artificial intelligence applications support clinical decision-making, predict treatment outcomes and identify optimal intervention strategies for individual patients^[10]. Virtual reality systems provide immersive therapeutic environments that enhance motivation, improve motor learning and enable precise movement training^[11].

This paradigm shift extends beyond technological integration to

encompass broader changes in care delivery models, patient-provider relationships and outcome measurement approaches. Contemporary rehabilitation emphasizes patient empowerment, shared decision-making and self-management capabilities while maintaining clinical rigor and evidence-based practice standards ^[12]. The traditional clinic-based, therapist-directed model is evolving toward hybrid care systems that combine in-person expertise with digital tools and remote monitoring capabilities ^[13].

Understanding these emerging trends is essential for rehabilitation practitioners seeking to optimize patient outcomes while adapting to evolving healthcare landscapes. This chapter examines the most significant contemporary developments in musculoskeletal rehabilitation, synthesizing current evidence, implementation strategies and future directions to guide clinical practice evolution.

Chapter Content

Digital Health Technologies in Rehabilitation

Digital health technologies have fundamentally transformed musculoskeletal rehabilitation delivery, creating new paradigms for patient assessment, treatment implementation and outcome monitoring. These technologies encompass a broad spectrum of tools including mobile applications, web-based platforms, wearable devices and integrated care management systems that collectively enhance rehabilitation accessibility and effectiveness ^[14].

Contemporary digital health platforms provide comprehensive rehabilitation ecosystems that integrate patient education, exercise prescription, progress tracking and clinician communication within unified interfaces. These systems enable personalized exercise libraries, automated progression algorithms and real-time feedback mechanisms that support patient engagement and adherence ^[15]. Evidence demonstrates that digital health interventions can achieve clinical outcomes comparable to traditional face-to-face rehabilitation while reducing costs and improving accessibility ^[16].

Mobile health applications represent a particularly significant development, with over 350,000 health-related apps currently available across major platforms ^[17]. Musculoskeletal-focused applications provide features including symptom tracking, exercise guidance, pain monitoring and educational resources that support patient self-management capabilities. Validated applications such as Kaia Health and Sword Health have demonstrated significant improvements in pain, function and quality of life

outcomes across diverse patient populations^[18].

Wearable sensor technologies enable continuous monitoring of movement patterns, activity levels and physiological parameters that inform rehabilitation planning and progression. Inertial measurement units, accelerometers and gyroscopes provide objective data on range of motion, movement quality and exercise compliance that enhance clinical decision-making^[19]. Recent studies demonstrate strong correlations between wearable sensor data and traditional clinical assessments, supporting their integration into routine practice^[20].

The integration of digital health technologies with traditional rehabilitation approaches creates hybrid care models that optimize both technological capabilities and human expertise. These models typically combine remote monitoring and digital tools with periodic in-person assessments, enabling continuous care while maintaining therapeutic relationships^[21]. Research indicates that hybrid approaches may achieve superior outcomes compared to either purely digital or traditional care models alone^[22].

Telerehabilitation and Remote Care Delivery

Telerehabilitation has emerged as a clinically validated alternative to traditional in-person rehabilitation, offering comparable outcomes while addressing accessibility barriers and improving care continuity^[23]. This modality encompasses synchronous video consultations, asynchronous exercise monitoring and comprehensive digital care platforms that enable remote assessment, treatment and follow-up^[24].

Clinical evidence consistently demonstrates the effectiveness of telerehabilitation across diverse musculoskeletal conditions. Systematic reviews and meta-analyses report equivalent outcomes in pain reduction, functional improvement and patient satisfaction when comparing telerehabilitation to conventional care^[25]. Conditions showing particularly strong evidence for telerehabilitation effectiveness include low back pain, neck pain, knee osteoarthritis and post-surgical rehabilitation^[26]²⁶.

The implementation of effective telerehabilitation requires systematic approaches to patient assessment, treatment delivery and outcome monitoring adapted for digital environments. Virtual physical examinations utilize structured protocols that combine patient history, visual observation and guided self-assessment techniques to achieve diagnostic accuracy comparable to in-person evaluations^[27]. Special tests can be effectively adapted for self-performance or caregiver assistance under therapist

guidance^[28].

Treatment delivery in telerehabilitation emphasizes patient education, exercise prescription and self-management support rather than hands-on interventions. Therapists utilize screen sharing, video demonstrations and real-time feedback to guide exercise performance and movement correction^[29]. Household objects and readily available equipment replace specialized therapeutic tools, requiring creative adaptation of traditional interventions^[30].

Quality assurance in telerehabilitation involves establishing technical requirements, safety protocols and clinical standards that ensure effective and safe care delivery. Essential components include stable internet connectivity, appropriate camera positioning, adequate lighting and clear communication protocols^[31]. Safety considerations encompass fall risk assessment, emergency procedures and clear guidelines for when in-person evaluation is necessary^[32].

Patient satisfaction with telerehabilitation consistently exceeds 80% across multiple studies, with particularly high ratings for convenience, accessibility and communication quality^[33]. Barriers to implementation include technology literacy, equipment availability and regulatory considerations that vary by jurisdiction^[34]. Successful telerehabilitation programs typically provide technology training, equipment support and clear protocols for technical difficulties^[35].

Artificial Intelligence and Machine Learning Applications

Artificial intelligence and machine learning technologies are revolutionizing musculoskeletal rehabilitation through enhanced diagnostic accuracy, personalized treatment planning and predictive outcome modeling^[36]. These technologies analyze complex datasets to identify patterns, predict treatment responses and optimize intervention strategies with precision exceeding traditional clinical approaches^[37].

Machine learning algorithms demonstrate remarkable capability in movement analysis and biomechanical assessment. Computer vision systems can analyze video recordings to assess movement quality, identify compensatory patterns and track progress with accuracy comparable to expert clinical observation^[38]. These systems provide objective, reproducible assessments that enhance clinical decision-making and reduce inter-rater variability^[39].

Diagnostic applications of artificial intelligence show particular promise

in musculoskeletal imaging interpretation. Deep learning algorithms achieve diagnostic accuracy exceeding 90% for common conditions including fractures, osteoarthritis and soft tissue injuries when analyzing radiographs, MRI and ultrasound images^[40]. These tools support clinical decision-making while reducing diagnostic delays and improving consistency^[41].

Treatment personalization represents another significant application area, with machine learning models analyzing patient characteristics, symptom patterns and treatment responses to predict optimal intervention strategies. These models consider multiple variables including demographics, comorbidities, psychosocial factors and biomarkers to recommend individualized treatment protocols^[42]. Studies demonstrate improved outcomes when treatment decisions are guided by machine learning predictions compared to standard clinical approaches^[43].

Predictive modeling applications enable proactive identification of patients at risk for poor outcomes, treatment non-adherence or complication development. These models analyze historical data, current symptoms and behavioral patterns to generate risk scores that inform clinical decision-making^[44]. Early intervention based on predictive models can prevent complications and improve long-term outcomes^[45].

The integration of artificial intelligence into clinical workflows requires careful consideration of implementation strategies, validation processes and ethical implications. Successful implementation typically involves gradual integration, comprehensive training programs and ongoing performance monitoring^[46]. Ethical considerations include data privacy, algorithmic bias and maintaining appropriate human oversight of automated recommendations^[47].

Virtual and Augmented Reality Technologies

Virtual and augmented reality technologies provide immersive therapeutic environments that enhance motivation, improve motor learning and enable precise movement training in musculoskeletal rehabilitation^[48]. These technologies create engaging, interactive experiences that can improve patient adherence while providing objective outcome measures^[49].

Virtual reality applications in rehabilitation span multiple domains including pain management, movement retraining and functional skill development. Immersive environments can distract from painful stimuli while providing controlled settings for therapeutic exercise and movement practice^[50]. Studies demonstrate significant pain reduction and improved function when virtual reality is integrated into rehabilitation protocols^[51].

Movement training applications utilize virtual reality to provide real-time feedback on movement quality, timing and accuracy. These systems can simulate functional activities, provide visual and auditory cues and adjust difficulty levels based on patient performance^[52]. The immersive nature of virtual reality environments enhances motor learning through increased engagement and motivation^[53].

Augmented reality technologies overlay digital information onto real-world environments, providing guidance and feedback during exercise performance and daily activities. These systems can display movement trajectories, provide corrective cues and track progress in real-time^[54]. Augmented reality applications show particular promise for home-based rehabilitation where immediate therapist feedback is unavailable^[55].

Clinical evidence supporting virtual and augmented reality applications continues to grow, with systematic reviews demonstrating significant improvements in pain, function and quality of life across diverse patient populations^[56]. Conditions showing strong evidence for virtual reality effectiveness include chronic pain, post-stroke rehabilitation and orthopedic recovery^[57].

Implementation considerations for virtual and augmented reality technologies include equipment costs, technical requirements and patient acceptance factors. While initial costs can be substantial, decreasing hardware prices and improving accessibility are expanding implementation opportunities^[58]. Patient acceptance is generally high, particularly among younger demographics, though comprehensive orientation and support are essential for successful adoption^[59].

Precision Medicine and Personalized Rehabilitation

Precision medicine approaches in musculoskeletal rehabilitation utilize individual patient characteristics, biomarkers and genetic profiles to optimize treatment selection and outcomes^[60]. This paradigm shift from one-size-fits-all protocols to individualized interventions represents a significant advancement in rehabilitation science^[61].

Biomarker identification and utilization enable more precise treatment targeting and outcome prediction. Inflammatory markers, pain mediators and tissue healing indicators provide objective measures for treatment planning and progress monitoring^[62]. Recent research identifies specific biomarker profiles associated with treatment responsiveness, enabling more accurate intervention selection^[63].

Genetic profiling applications in rehabilitation focus on variants affecting pain sensitivity, inflammation response and tissue healing capacity. Polymorphisms in genes regulating cytokine production, collagen synthesis and pain perception influence treatment outcomes and recovery trajectories^[64]. Genetic information can guide analgesic selection, exercise prescription and realistic expectation setting^[65].

Phenotyping approaches classify patients into subgroups based on clinical presentation, symptoms patterns and functional characteristics rather than traditional diagnostic categories. This classification system enables more targeted treatment approaches and improved outcome prediction^[66]. Examples include pain phenotyping for chronic conditions and movement pattern classification for injury prevention^[67].

Psychosocial profiling recognizes the significant impact of psychological and social factors on rehabilitation outcomes. Validated screening tools identify patients with fear avoidance behaviors, catastrophizing tendencies or low self-efficacy who require modified treatment approaches^[68]. Incorporating psychosocial interventions based on individual profiles improves overall treatment effectiveness^[69].

The implementation of precision medicine approaches requires comprehensive assessment protocols, validated screening tools and integrated care teams. Successful programs typically involve interdisciplinary collaboration between rehabilitation specialists, physicians, psychologists and other healthcare providers^[70]. Data integration platforms enable synthesis of multiple information sources to guide personalized treatment planning^[71].

Advanced Assessment and Monitoring Technologies

Contemporary musculoskeletal rehabilitation increasingly relies on advanced assessment technologies that provide objective, reliable and comprehensive evaluation of patient status and progress^[72]. These technologies enhance clinical decision-making while reducing assessment variability and improving outcome documentation^[73].

Wearable sensor systems provide continuous monitoring of movement patterns, activity levels and physiological parameters relevant to rehabilitation progress. Accelerometers, gyroscopes and magnetometers capture detailed kinematic data that inform treatment planning and progression decisions^[74]. Studies demonstrate strong correlations between wearable sensor measurements and traditional clinical assessments across multiple parameters^[75].

Motion capture technologies enable precise three-dimensional analysis of movement patterns, joint kinematics and muscle activation patterns. These systems provide detailed biomechanical assessments that identify movement dysfunctions and track treatment progress with high precision ^[76]. Portable motion capture systems are making this technology more accessible for clinical applications ^[77].

Ultrasound imaging applications in rehabilitation include muscle thickness measurement, tendon visualization and real-time biofeedback during exercise performance. Point-of-care ultrasound enables immediate assessment of tissue quality and treatment response⁷⁸. Training programs are expanding access to ultrasound technology among rehabilitation professionals ^[79].

Force measurement systems provide objective assessment of strength, power and movement quality parameters that guide treatment progression and return-to-activity decisions. Portable force plates, handheld dynamometers and force sensors enable objective strength testing in diverse clinical settings ^[80]. These measurements show superior reliability compared to traditional manual assessment techniques ^[81].

Functional assessment technologies focus on task-specific performance measurement rather than isolated impairment testing. These systems evaluate complex movement patterns, balance responses and functional capacity under various conditions ^[82]. Functional assessment results demonstrate stronger correlations with real-world performance compared to traditional impairment measures ^[83].

Integration Challenges and Implementation Strategies

The successful integration of emerging trends in musculoskeletal rehabilitation requires systematic approaches that address technical, clinical and organizational challenges ^[84]. Implementation strategies must consider workflow integration, training requirements, cost considerations and patient acceptance factors ^[85].

Technical integration challenges include interoperability between different systems, data management requirements and cybersecurity considerations. Successful implementations typically utilize standardized protocols, secure data transmission methods and comprehensive backup procedures ^[86]. Integration with existing electronic health records and practice management systems is essential for workflow efficiency ^[87].

Clinical integration requires evidence-based protocols, comprehensive

training programs and ongoing quality assurance measures. Practitioners need training in new technologies, assessment techniques and treatment approaches to ensure safe and effective implementation ^[88]. Continuing education programs and certification processes support skill development and maintain clinical standards ^[89].

Organizational factors including leadership support, resource allocation and change management strategies significantly influence implementation success. Organizations with strong leadership commitment, adequate resources and systematic change management approaches achieve better implementation outcomes ^[90]. Staff engagement and stakeholder buy-in are essential for sustainable adoption ^[91].

Patient acceptance and engagement factors require careful consideration of demographics, technology literacy and cultural preferences. Successful programs provide comprehensive orientation, ongoing support and flexible implementation approaches that accommodate diverse patient needs ^[92]. Cultural competency and language accessibility are essential considerations for equitable implementation ^[93].

Cost-effectiveness analyses demonstrate positive return on investment for most emerging rehabilitation technologies when implemented appropriately. Initial implementation costs are typically offset by improved efficiency, reduced complications and enhanced outcomes ^[94]. Long-term economic benefits include reduced healthcare utilization and improved productivity outcomes ^[95].

Future Directions and Emerging Opportunities

The future of musculoskeletal rehabilitation will likely involve further integration of emerging technologies, expanded personalization capabilities and novel therapeutic approaches currently in development ^[96]. Several key trends are poised to significantly impact clinical practice over the next decade ^[97].

Nanotechnology applications in rehabilitation may enable targeted drug delivery, enhanced tissue repair and improved implant integration. Nanoparticle systems can deliver therapeutic agents directly to injured tissues while minimizing systemic effects ^[98]. Smart materials incorporating nanotechnology may provide responsive support systems that adapt to patient needs ^[99].

Regenerative medicine integration with rehabilitation focuses on optimizing tissue healing and functional recovery through combined

biological and mechanical interventions. Stem cell therapies, platelet-rich plasma and growth factor treatments show promise when combined with specific rehabilitation protocols^[100]. Timing and type of mechanical loading appear critical for optimizing regenerative outcomes^[101].

Brain-computer interface technologies may enable direct neural control of assistive devices and provide novel approaches to motor learning and neuroplasticity enhancement. These systems could revolutionize rehabilitation for individuals with neurological impairments while providing insights into motor control mechanisms^[102]. Early research demonstrates feasibility for clinical applications^[103].

Robotic rehabilitation systems continue advancing toward more sophisticated, adaptive and affordable platforms. Next-generation robots may provide personalized assistance, real-time feedback and autonomous treatment delivery while maintaining safety and therapeutic effectiveness^[104]. Home-based robotic systems may expand access to advanced rehabilitation technologies^[105].

Predictive analytics and population health applications will likely expand to enable proactive intervention strategies and population-level outcome optimization. Machine learning models may identify individuals at risk for musculoskeletal problems before symptoms develop, enabling preventive interventions^[106]. Population health approaches may optimize resource allocation and improve overall health outcomes^[107].

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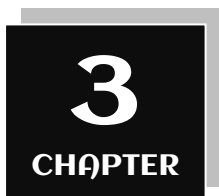
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3 CHAPTER

Indian Gaming Industry and Its Role in Development of Economy: A New Avenue for Indian Economy

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Abstract

The gaming industry at international maps is growing with a very high optimism in case of economy. The industry is so big that it has surpassed film and music industry in regard of its size. The purpose of this study is to unveil the economics of gaming industry worldwide, especially in Indian Economy. This study also intends to find the role of gaming industry in India's economic development for the future, especially for Mission "Viksit Bharat 2047". To achieve the objectives of this study, descriptive research design is used by the researcher under which a bibliographic review has been taken of reports, blogs and research articles. Various challenges and opportunities for Indian gaming industry have been studied under his paper. To conclude the article it is found that due to the increasing number of Smartphone users, higher internet speed and capacity of gaming sector to be fulltime career for youths, the gaming industry of India is growing very positively. It is also found that India's gaming market is expected to grow to \$1.4 billion in 2026 from \$704.5 million in 2022.

Keywords: Gaming, Economy, Viksit Bharat, Esport, gamevertising, AI, VR.

Introduction

India has seen positive development in case of economy as compared to the time of independence. The country was struggling for its daily expenses at the time of independence and also had a very low literacy rate. The literacy rate at that time was only 12%. The condition of businesses and

industries was also not good. The condition of India's economy was so bad that the Gross Domestic Product at that time was 2.7 lac Crores, which was only 3% of world's GDP and the country was counted in the list of poor and underdeveloped countries (*75 Years of India's Independence: A Short History of Indian Economy* | *Economy News, Times Now*, n.d.)(*75 Years of India's Independence: How Indian Economy Has Fared since 1947* | *Today News*, n.d.). Presently India has proved as one of the developing countries of the world. India ranks as the world's 5th largest economy with GDP of \$3.9 Trillion. The present growth rate of Indian GDP is calculated to 8.2% for the financial year 2024. With this, per capita GDP is also substantially increased to \$ 2730 as compared to \$83 in 1960 (*GDP Of India: Current And Historical Growth Rate, India's Rank In The World - Forbes India*, n.d.). Due to this up trending economic growth, India's market is calling world players to invest and business in India. This journey from being one of the underdeveloped, poor countries of the world having GDP of 2.7 lakh crore, which was merely 3% of world's GDP, to the fifth largest economy in the world has contributed by many industries and strategic happenings throughout the time. As part of this development many industries in India have contributed and still contribute to this development. One of the major industries in this run down is the steel and iron industry of India which provides job opportunities to more than 2.5 lakh workers and it is one of the biggest 10 steel and iron industries in the world. Further textile industry, jute industry, automobile industry, petrochemical industry has also contributed to India's economy to achieve this place. Further, the IT industry of India is presently the most prosperous industry in India economy (Elizabethrani, 2019). The IT sector of India, though being lately introduced, is proving itself as one of the major parts of Indian industries worldwide. It is exporting 20% of the software and services to the world (Jalaja Enamal, 2020). It can be seen from the above evidence that today's economic development of India is supported and complemented by many industries.

The future roadmap for the Indian economy is also now set by the present government laid by India's Hon PM Narendra Modi. The Finance Minister, Nirmala Sitaraman during the Union Budget 2024 presentation, underlined the future plans for achieving economic development under the title of "*Mission Viksit Bharat, 2047*". *Mission Viksit Bharat, 2047* aims to transform India to a developed country till 2047, the 100th year of Independence. Nine priorities have been announced by the Finance Minister in case of accomplishing the mission. These priorities range from productive measures in agriculture to next gen reforms(*Viksit Bharat @ 2047*, n.d.)(*Budget 2024: Sitharaman Outlines 9 Priorities for "Viksit Bharat*

2047” Goal | Budget 2024 News - Business Standard, n.d.). To achieve this goal of being the third largest economy in the world and transforming India to a developed country, both traditional and new evolving industries have to leverage better results. Traditional industries where the country is relying on have to continue and accelerate the performance as well as new industries which are contributing worldwide have to be adopted and concentrated for achieving the goal of *Viksit Bharat 2047*. One of the modern industries which have potential to supply enormous jobs and to provide a pathway for economic development is Gaming Industry. On the international maps, the gaming industry has shown positive numbers in case of employment generation and economic attainments.

From merely entertaining the masses to a field of huge employment and earning possibilities, the gaming industry has changed the perspective towards it. Gaming is also known as *Esport* or electronic sports which is supported by machines and complemented by human computer interaction (Palma-Ruiz et al., 2022). World’s gaming market is divided according to many segments in this industry as console gaming, Smartphone and tablet gaming and offline and browser based gaming. This division of the market is done on the basis of gadgets and platforms which are used for gaming worldwide. The gaming market globally is expected to grow to \$397.21 billion till 2029. This growth rate is as high as any other mainstream industry in the world(*Gaming Industry Growth - Market Share & Size*, n.d.). With this rapidly growing industry of gaming, gaming is increasing in India also. This paper intended to study whether the Indian gaming industry is also growing with the same pace and will this industry contribute to the *Viksit Bharat, 2047* by any means. The paper intended to find out answers to questions like; what is the size of the Indian gaming industry, what will be the future of the Indian gaming industry in business’s perspective, does this industry help in providing jobs and many more. The study was carried out for fulfilling following objectives;

- ✓ To study the Present Global Gaming Industry.
- ✓ To study the Present Gaming Industry of India.
- ✓ To predict growth of gaming in India.
- ✓ To study the economics of the Gaming Industry in India.
- ✓ To Study the impact of Gaming industry on employment generation.

Methods

As the researcher intended to describe the present and future of the gaming industry, a descriptive type of research design is used for the paper. Under this study the description of the global gaming industry and Indian gaming industry is done by the researcher. Further the role of the gaming industry is also being studied by the researcher from an economic perspective. How the economy and employment is affected by the gaming industry has also been studied and described by the researcher. The data has been created by secondary sources. Most of the data for the study is taken from various industry reports worldwide and research articles written by researchers throughout the world. Further the data is qualitatively analyzed for furnishing the results and conclusions.

Results and Discussions

Worldwide Gaming Industry and its Economics at a Glance:

The gaming industry worldwide is growing at a very rapid speed. With the increase in mobile users and high speed internet penetration, the number of players is also increasing worldwide and so the industry is growing. The way of gaming has drastically changed in the last twenty years from a crude type to a 3 dimensional way of gaming. This transformation of gaming got through use of mobile, cloud gaming to a very new avenue of virtual reality in gaming. The gaming industry is so huge and big that every 1 of three people will say he or she is playing or watching a game today. Further it can be seen that the gaming industry is almost double in size as compared to music and film industry combined. Gaming worldwide has become so popular that it has surpassed all sports except soccer. In these gaming patterns, mobile gaming proved the most played way of playing games followed by PC and gaming Consoles(Shaw et al., 2020).

The growth of the gaming industry will continue for the future as the revenue from games is projected to reach \$ 312 Billion in 2027 from \$262Billions in 2023. This growth estimation is backed up by many aspects related to this industry (Jon Wakelin, n.d.). One of the aspects which are helping this industry to grow is the simplified gaming and traditional platforms like PC and gaming Consoles as these platforms are accepting new technologies and making gaming easy for the gamers. The second reason for this situation in the gaming industry is gaming organizations are developing their own games on cloud. The gamers now need to be dependent on PC or consoles. The profit of the gaming industry is now being distributed amongst the publishers as well as distributors, mobile ad techs and it also invested in more innovations in gaming. The increasing opportunity for every

stakeholder is the third of the reasons for the growth of gaming. Due to higher prospects of earning profits from playing games is the next aspect which is boosting the industry. The next reason for this boost is the additional benefits of game-tech companies by using the created aspects for another industry. The game-tech companies now can use the same graphics for another purpose like films or advertisements. Animated videos and images are now being used in many other industries is also a big reason for growing gaming. In this way there are many aspects which are shaping the growth of the gaming industry worldwide. This type of supporting ecosystem is complementing the gaming industry in almost all developed countries. Though, the facilities of popular gaming consoles like Xbox and PlayStation are upgraded, still these are proven to be *not the best* way of gaming because of the emergence of mobile gaming especially with touch screen mobile. The industry transformation is highly affected by the emergence of Smartphone in the world. When it comes to innovative trends in gaming industry, Virtual Reality is at higher place (Liang, 2022). Talking about the United States gaming industry, it is segmented into many segments and contributes to the US economy by providing many jobs in the states (Grueber & Yetter, 2024). US gaming industry is defined with the help of many segments as video game software firms, video game consoles, peripherals and hardware firms, support services, video game retail outlets and other video game specific activities. These all segments are called the video game industry of US as united. The major impact of gaming industry on US economy in regards of employment generations is necessary to study here. The US video gaming industry provides employment to more than 1,04,000 US employees, amongst them software segment (game developers and studios) plays a major role in providing employment in gaming industry. During 2017 to 2019, China found to be the highest revenue seeking country in the world gaming market with \$37.2 Billion, almost 69% of the world revenue from the world gaming industry. The United States followed China in this regard with 34.10\$ of the revenue accounting to \$17.90 Billion followed by Japan which was having a share of 15.25%, almost \$17.90 Billion. In case of region wise analysis, eastern Asia found for having highest share during the period. The European countries were also found to be greater markets for gaming in the world (Palma-Ruiz et al., 2022).

Indian Gaming Industry and Indian Economy:

Recently India has overtaken China in terms of population in the world. This trend is going to be the same until 2050 (Hertog et al., 2023). This

increased population can also be input for the country's economic growth and so for the gaming industry of India. Youths are turning to gaming not merely as a hobby but also as a career path. Gaming is now not limited to hobby only but it has proven that it is a way of making a penny and it can be taken seriously as a career in this period of time (Ankit, 2020). The Indian Gaming industry possesses the potential for being a mainstream industry until 2025 and will be contributing to employment generation and economic growth in the country. The Covid-19 lockdown made people accept new ways of connecting socially and getting entertained, this situation strengthened the gaming industry in India at the initial stage (Dey Kushal, 2020). Despite facing many challenges, the Indian gaming industry has shown great signs of development because of the supporting aspects to it in India (Kumar, 2021). The gaming industry in India has faced many challenges at the initial stage. These challenges include its lack of presence as a career option in the minds of people. Gaming was considered to be a leisure activity and never got the seriousness like a career option. Hence it has restricted itself from getting a serious outlook in the country. Another challenge before gaming industry in India is the mindset of society. Society's approach towards the players who play games was never good hence it was supposed to be a bad habit. Despite facing these challenges, the user base is projected to be 500 plus million gamers in India. The reasons behind the changing outlook towards gaming and increased gamers in India are also playing their role. The customized content in games is one of the reasons for the growing popularity of games in India. It can be easily seen in a game that adopts the Indian festivals and emotions. Second and important reason for this growth is the increased number of Smartphone users and internet penetration in India. Due to the availability of cheaper and speedy internet, the Smartphone is taking the place of almost all entertainment options. It has found that in the year 2018, India was having the base of 450 Million internet users almost 40% of the country's total population (Shinde, 2024). This has led to increased gamers and gaming in the country. One of the major reasons for growth of gaming in India is the career option it is providing to the gamers. The youth now don't want to stick to a 9-5 job; hence he or she is searching for other career options which offer freedom of time. Gaming allows users to earn money as and when they want. Other reasons for this growth ranges from availability of multiple platforms of gaming, increase in cloud based gaming to the instant reason of lockdown in India. The investments are also getting increased in the Indian gaming industry after seeing the potential for growth in it (Kumar, 2021). In this way, despite many challenges and obstacles at one side and supporting

situations at another, the Indian gaming industry has emerged as one of the profit avenues for business.

India, with 568 million gamers and 9.5 billion gaming apps, has become the largest gaming market by surpassing China and US in case of user base. This percentage of game downloads has surpassed Brazil and the US in combined. This shows that the gaming industry and gamers in India are growing at a faster pace. In regards to economic aspects of gaming, it is also estimated that the gaming market in India will reach more than \$7 billion until 2028(*India's Gaming Industry Powers up - The Economic Times*, n.d.). Substantial increase in revenue of online gaming India has seen in 2023 as compared to 2018. In the year 2018, the revenue of online gaming in India was Rs. 43.8 Billion. In 2023, it has increased to Rs. 118.8 Billion, almost 271% increase have been seen. One of the major motives for playing the game in India is streaming these sessions online and monetizing it as a source of income. The major by-product of gaming industry in India is streaming of gaming.. This streaming business and its revenue are expected to grow to RS. 82.35 Millions in 2025 as compared to Rs. 39.27 Millions in 2023. The streaming of videos comes under the umbrella of content creation. Creating content and using it on digital media is one of the features of developing the Gig Economy in India which can lead to increased job opportunities remotely(Amrutao, 2023). Actual E-sport in India is not yet that much practiced as compared to other countries like China and US, still it has shown a great sign by increasing the revenue of it 29% from 2020 to 2021. One of the positive things for the gaming industry in India is the increasing interest of investors in the gaming industry. Many companies are now investing in the gaming industry as they can predict a better future for gaming as a business avenue. The investments in the gaming industry in India were Rs. 415 Million in 2020 which is increased to Rs. 1744 million in 2021, almost four fold (Narayanan et al., 2023). The gaming sector of India is also boosting the tax sources for the government. The goods and services tax rate for the gaming industry is 28% now. The taxes collected from the sector are really good to analyze and study the role of the gaming industry in India's growing economy. According to the interview of CBIC Chairman, the GST collection from this sector before October 2023 was around Rs. 250 crores a month, but after the new tax rates the GST collection from the segment is consistently approaching to the around Rs. 1100 crores per month, it has even crossed Rs. 1300 crores for the recent month (Surabhi, n.d.). Number of gamers and profit potential in gaming is increasing and so the gaming companies in India are also marginally increased from 25 in 2010 to more than 275 in 2020 (Patil & Bachan, 2022). It is expected that the

Indian gaming market will reach to \$1.4 billion in 2026 as compared to \$704.5 million in 2022 with the growth rate of 21.1% CAGR. To conclude this section it can be said that the Indian gaming industry has shown good signs for getting recognised as the mainstream industry in India. Due to its increasing popularity in Indian gamers and its ability to provide financial career for youths, the industries, gamers, are also increased prominently. In regards to financial aspects also, the industry has shown that it will have as much flourishing industry in future as other mainstream industries.

The future trends will shape the gaming industry in all new possibilities in this sector. Due to its highly lucrative profit potential, many new organizations are investing into the industry and so the developments are promising. One of the major trends in Indian gaming industry will be the application of AI, VR, experiential experiences and Metaverse to enhance the creativity and excitement in gaming (iDGS, 2023) (*How India's Gaming Creator Economy Contributes to a Billion-Dollar Gaming Market - Brand Wagon News | The Financial Express*, n.d.). The role of games is also increasing in the case of advertising a product and creating a customer base from that. The gaming industry is attracting the marketers also as game marketing has shown greater results. Whereas one of the new trends that will help gaming grow is “Gamevertising”, marketing a product or service via video game content. Gamevertising is also called in game branding and experiences to the players. This advertising phenomenon goes beyond merely placing a product through media but it gives extra edge to product and marketer with its capacity of experiential storytelling (Major, n.d.). One of the major reasons why the Indian gaming industry will show greater results lies in India's growing population. The more the population, the more will be the gamers and so the market. It is expected that the population of people from age 15-59, probable gamers, will be 64.8% in 2026 and it will grow in 2031 to 65.1(Population Statistics, 2022). It shows that the potential for increasing the number of gamers in India is high and so is the potential of the Indian gaming industry. To conclude the section it can be said that the increasing number of gamers, adoption of Ai and VR to gaming and potential for gaming advertising are the factors which can fuel the gaming industry in near future.

Conclusion

India's journey towards becoming world's fifth largest economy in the world has been supported by many industries throughout history. Almost every industry, including agribusiness and allied industries to the presently booming IT industry, has contributed positively in India's economic

development. The present government has shown aggressive moves to develop the economy of country and to reach at the level of third largest economy in the world till 2047, the 11th anniversary of independence. This mission is known as “*Viksit Bharat, 2047*”.

To achieve this goal of getting promoted to third largest economy in the world, economy has to be supported by traditional and modern industries. One of the modern industry which is showing very good signs worldwide is online gaming industry. The online gaming industry worldwide is so grown that it has surpassed the world film and business industry. The growth rate of the industry is also overwhelming. This industry is particularly grown to a level in the countries like China and the US. It has contributed to raise employment as well as economic growth in these countries. The numbers of gamers who play games in its countries are at high numbers and so the industry.

Recently, India overtook China in case of population and become the country with highest population. This trend of highest population will be continued for a long time. This increased population of India will result in more number of gamers in India and so the Indian gaming industry, which is growing presently also, will fuel up and will grow aggressively in the future. The supporting aspects are so good for the Indian gaming industry that despite of challenges faced, the industry is growing. Youths, with a changed perspective, are choosing freelancing and gaming as their fulltime career instead of 9-5 job. Further, the increasing number of Smartphone and high speed internet penetration, the gaming will be growing in India in the coming Years. It can be assured that, due to the increased inputs in gaming industry in form of investments and gamers, the India gaming industry will support the Viksit Bharat mission by complimenting the economy and by providing job opportunities.

The gaming industry is growing worldwide. Gaming platforms and games have been also used for presenting the advertisement to the probable audiences. The intrusion of product and service advertisement is one of the area which can be studies in coming days. Gamevertising is the word which is being in boom from few months and it will be a good avenue for future research.

Future Scope of the Study

The gaming industry is growing worldwide. Gaming platforms and games have been also used for presenting the advertisement to the probable audiences. The intrusion of product and service advertisement is one of the

area which can be studies in coming days. Gamevertising is the word which is being in boom from few months and it will be a good avenue for future research.

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4 CHAPTER

A Study of George Eliot's Works through Agnostic Perspective

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Introduction

Victorian literature reflects the impact of science on faith throughout that age. Throughout Victoria's reign, religious unrest simmers among journalists, poets and novelists alike. Victorian literature reflects the impact of science on faith throughout that age. Paley, a utilitarian, asserted that the changes were too gradual to be noticed, whereas "natural" theologians with a scientific bent had maintained that creation needed a creator. Charles Dickens, W. M. Thackeray, Kingsley, Elizabeth, Gaskell, Charlotte Bronte, Emily Bronte, Anne Bronte, George Meredith and George Eliot were among the novelists who embraced the era's changes, advancements and developments as well as its squalid conditions. They also portrayed all human emotions with warmth and made many predictions for the enemies.

The intellectual environment of this period gave George Eliot a new sight and perspective towards many dimensions of life and Christian religion. Gradually, the foundations of reflective thinking and her philosophical theories began to be established. Those influence reached her in state where she did not like any religious principles as true, who did not follow in immortality or God and who refused Christianity as a historic or dogmatic belief, to accept so much as she did of the better essence of religion and to be so keenly in affinity with it. It was from the general agnosticism and elegance of the times she felt to deny all religion as false to truth and as not throw out a just interpretation of life and its facts.

Keywords: Perspective, Cristian, Perspective, Religion etc.

Agnosticism is a philosophical position that holds that the existence of God, the divine or the supernatural is unknown and perhaps unknowable. It is

the view that human beings are unable to definitively prove or disprove the existence of a higher power or ultimate reality. Agnosticism does not deny the possibility of such existence but asserts that there is not enough evidence to make a conclusive judgment.

The themes of Christianity and agnosticism are intricately entwined with George Eliot's examination of society, morality and human nature in her works. Eliot's complicated depiction of religious conviction and doubt in her writing was impacted by her early religious background and her intellectual shift towards secular humanism. Growing up in a profoundly pious Anglican family, Eliot was personally strongly involved with Christian doctrine. Her opinions changed as she grew older, though, as a result of Enlightenment concepts, German higher criticism of the Bible and the philosophical writings of intellectuals such as David Strauss and Ludwig Feuerbach. She adopted agnosticism and turned away from traditional Christianity in favour of humanistic principles. Her works, in which characters frequently struggle with religious conviction, moral quandaries and the conflict between faith and reason, reflect her personal journey. Eliot handles Christianity in a complex way. She admires the moral and ethical precepts of Christianity, especially those that emphasize compassion, generosity and community, even as she criticizes the dogmatism and rigidity of organized religion.

Eliot's characters frequently struggle with religious skepticism and the pursuit of truth outside of conventional Christian teaching. Tom and Maggie Tulliver serve as opposing viewpoints on religion and morals in *The Mill on the Floss*. Maggie specifically struggles with issues of religion, responsibility and the boundaries of religious instruction. Eliot's own journey from faith to doubt is reflected in her emotional and intellectual problems. George Eliot asserts that religion is based on emotion, human relationships with one another and man's irrevocable relationships with the cosmos. In *The Mill on the Floss* she has given a definition of it, in speaking of Maggie's "want of that knowledge of the irreversible laws within and without her, which, governing the habits, becomes morality and developing the feelings of submission and dependence, becomes religion" (*Mill on the Floss*).

Eliot always placed the most emphasis on the moral aspects of the topic and her views were probably greatly influenced by Kant's viewpoint. At the very least, she came to believe that all intellectual musings on the matter are pointless and found ultimate fulfilment in agnosticism. She believed that moral action might resolve life's issues when no other solution could and her moral convictions grew stronger at the same time. She now agreed with Kant, not Comte, that the only trustworthy source of guidance is moral nature. When

Fichte's English disciple Matthew Arnold talked on the moral order of the world, she warmly agreed with him and supported the idea that righteousness is determined by the Eternal, not by us.

George Eliot was a rationalist and thinker who was unsatisfied with the supernatural and irrational aspects of conventional Christianity. No English writer of the era and most definitely no novelist, more perfectly captures the century, according to Basil Willey; her growth is a paradigm, her intellectual life a graph, of its most certain patterns. She kept up with the latest philosophical, religious and scientific theories of the day. The curve, which began with evangelical Christianity, progressed from ambiguity to a reinterpretation of Christ and a human religion that begins with God and concludes with duty.

Wagenknecht in the *Cavalcade of the English Novel* states that: "George Eliot's revolt against her inherited faith was based on intellectual ground alone; at no time was there a moral revolt" Given who she was, it was only natural that she would have dedicated the remainder of her life to upholding Christian morality free from supernatural interference. She considered any belief in the supernatural to be unthinkable and the Christian concept of God was unacceptable to her rationalist side. She also thought that the idea of the soul's immortality was implausible. She symbolized the entire situation of the religious temperament that has been severed from the old objects of worship and intellectual conceptions due to rationalism. She was obviously not a practicing Christian, but she was even more alienated from the faith of Jesus because of her disassociation from it. She was aware of the desire for righteousness, the necessity of renunciation and the necessity of losing one's life to obtain it. She also possessed the faculty of veneration, which allowed her to recognize the reality of the invisible, even though religious consciousness was primarily moral.

The religious tensions that motivate the characters' actions are always moral conflicts and George Eliot's novels are founded on moral ideals. They divide themselves into two groups. In some ways, similar to Janet's repentance. *Bade*, *Adam*. The right way is clear, *Silas Marner*. The characters are limited to doing what they think is right. Because people are tempted to act inappropriately instead, the conflict revolves around their fight between their values and weaknesses. It's *Silas Marner*. Silas is a selfless and compassionate person by nature, but his passion for money has perverted him. But in the end, his affection for the little *Eppie* has come to his rescue. Although *Godfrey* is a decent and well-meaning young guy, his resistance to accept the painful reality about himself has deformed him. Another example

of such a guy is Arthur Donnithrone in *Adam Bade*, however he is limited by his weakness. An evangelical preacher's influence saves the compassionate, idealistic Janet Dempster from alcoholism and hopelessness;

Hetty is a shallow, feeble egoist who only manages to reach the gallows for execution because of her weakness and pride. George Eliot did not hesitate to illustrate the punishment of the transgressor because he knew that the price of sin is unfathomable anguish. As Diana Neill puts it: Such moral determination gave to her novels a certain rigidity, but it also gave them power and significance. Sorrow was strictly determined, but by character, not by external factors. Her characters are caught in some unbreakable chain of causation: 'our deeds determine us as much as we determine our deeds' is an assertion fully justified by her novels.

Despite his rejection of religion, wonder, beauty and optimism, the austere rationalist George Eliot clung to an unwavering ethical code that demanded nothing more from good behavior than the somber satisfaction of doing the right thing. Virtue was actually its own. It would be venal to want more. An overzealous commitment to learning most likely diminished an imagination that had never been very active. It is plausible to attribute the novelist's eventual decline in popularity following the moralizing Victorian era to this shortcoming.

Eliot's own agnostic beliefs are reflected in Maggie's skepticism of religious ideology and her yearning for personal autonomy in *The Mill on the Floss*. Her feelings and experiences are valued more highly than religious doctrine, underscoring the agnostic focus on personal experience. Maggie is changed by her relationships with Tom, Philip and Stephen, demonstrating the agnostic conviction in the importance of interpersonal bonds.

Floss on the Mill In 1860, George Eliot's second full work was published. The development of Maggie Tulliver's personality traits—the protagonist and agnostic like George Eliot—is the main emphasis of the novel as a whole. Regardless of religious influence, Maggie's hardships result in moral and personal development. Her moral development and maturation happen independently of religion, demonstrating the potential for a nonreligious morality.

Maggie's life encompasses her childhood and adolescence, her adulthood and her tragic demise in the flooded Floss River. Maggie is a sensitive, passionate young lady with an insatiable desire for attention but also the capacity for deep love. When Maggie finally realizes how terrible renunciation is, the decisions she must make put her to the ultimate test. Maggie tries to

save her brother but eventually dies in the flood. In their final moments, a brother and sister are reunited; they were not split up before to their deaths. In the narrative, the large river is described to "flow forever onward and links the beatings of the world's mighty heart with the small pulse of the old English farms" (Mill on the Floss).

The author of *The Mill on the Floss's* autobiographical character Maggie explains her own complicated personality and how it greatly relates to her own life. The book has been referred to as the spiritual autobiography of Mary Ann Evans. There are several similarities between Maggie Tulliver's and Mary Ann Evans' lives, particularly in the book's opening chapters. Mary Ann Evans' early life experiences were still vivid in her memory when she penned this book, providing her with inspiration for her creative flexibility within the constraints of her design. She uses her recollections to provide the details that give her account of her early years such a poignant and naive joy.

Maggie is highly imaginative and sensitive and has childhood agnostic tendencies. She has a heart and a head and she picks things up faster than Tom does. She has a strong and vibrant imagination. She enjoys reading and has a talent for story telling that makes her characters seem to come to life. She spins fanciful tales of animal romances with animals like the spiders in the mill. She adds a feeling of mystery to the garden's circular pool.

The agnostic thought is expressed in Silas Marner that man is to expect no help and consolation except from his fellow-man. "In old days there were angels who came and took men by the hand and led them away from the city of destruction. We see no white-winged angels now. But yet men are led away from threatening destruction: a hand is put into theirs, which leads them forth gently towards a calm and bright land, so that they look no more backward; and the hand may be a little child's" (116).

In her novels, George Eliot engages deeply with both Christianity and agnosticism, portraying characters who wrestle with faith, doubt and morality in a rapidly changing world. While she critiques the dogmatism and hypocrisy often associated with organized religion, she also acknowledges the power of Christian values like compassion, charity and redemption. Eliot's ultimate message is that, whether through religion or secular humanism, individuals can find moral guidance through empathy, personal responsibility and the search for truth.

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5 CHAPTER

Pathogenesis, Therapy, Challenges and Future Perspectives of Inflammatory Bowel Disease: An Updated Review of Current Literature and Beyond

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Abstract

The incidence of inflammatory bowel disease (IBD), characterized by chronic gastrointestinal inflammation, has significantly increased over the last two decades. Concurrently, advancements in treatment strategies have accelerated, aiming not only to induce but also to maintain remission. Inflammatory bowel disease is a chronic disabling inflammatory process that affects young individuals, with growing incidence. The etiopathogenesis of IBD remains poorly understood. Current pharmacological treatments used in clinical practice like thiopurines or anti-TNF are effective but can produce significant side effects and their efficacy may diminish over time. In fact, up to one third of the patients do not have a satisfactory response to these therapies. Consequently, the search for new therapeutic strategies targeting alternative immunological pathways has intensified. Several new

oral and parenteral substances are in the pipeline for IBD. Recently, several novel medications, such as Ustekinumab, Infliximab and Vedolizumab, have emerged as potential options for inflammatory bowel disease management. Despite achieving some effects in clinical applications, these therapies are still plagued by inadequate response rates and adverse side effects. Recent advances in the management of IBD have led to a paradigm shift in the treatment goals, from targeting symptom-free daily life to shooting for mucosal healing. In this chapter, we have systemically reviewed the etiology, pathogenesis of IBD and highlighted the therapeutic applications and future perspectives. These novel approaches have the potential to overcome current therapeutic limitations in the treatment of IBD.

Keywords: Inflammatory Bowel Diseases, Crohn's Disease, Ulcerative Colitis, Chronic Gastrointestinal Inflammation, Apheresis Therapy, Anti-IL-12/23 Therapy.

Introduction

Inflammatory bowel disease (IBD) is a chronic disabling inflammatory process that affects mainly the gastrointestinal tract and may present associated extraintestinal manifestations. IBD includes both ulcerative colitis (UC) and Crohn's disease (CD). In UC, the inflammation takes place in the colon and rectum, is limited to the mucosa and always extends in oral direction from the rectum. CD can affect any part of the gastrointestinal tract (typically the ileocecal area) and is characterised by transmural inflammation and local complications like stenosis, fistulae and abscesses ^[1, 2].

Abdominal discomfort, persistent diarrhoea, fever, rectal bleeding and weight loss are among its symptoms, which are more common in young people and alternate between flare-ups and remissions. IBD is thought to affect up to 0.5% of the general population in western nations and its frequency is rising. Strong anti-inflammatory medications (corticosteroids, thiopurines, anti-tumor necrosis factor [anti-TNF] medicines, etc.) must be continuously used to treat IBD and hospitalisation or surgery is necessary to control its consequences. This has a major negative impact on people's quality of life and places a heavy financial strain on society due to the high expense of healthcare. It is projected that the direct expenses alone in Europe surpass €5.6 billion a year ^[3-5].

Because of its chronic nature and uncertain history, inflammatory bowel disease poses a substantial challenge to modern treatment. It frequently manifests as diarrhoea, cramping in the abdomen, anaemia, weight loss and exhaustion. Effective management techniques are essential due to its

increasing worldwide frequency, which endangers the patient's health and places a financial strain on the family. Although a number of variables, including genetic alterations, host immunological dysfunction, intestinal dysbiosis and environmental influences, have been linked to IBD, the etiopathogenesis of the disease is not fully understood [5, 6].

Over the past 20 years, there have been more alternatives for treating IBD and many patients are finding success with more recent treatments. Conventional treatments control symptoms through pharmacotherapy, surgical interventions are successful but cause remission in most patients and the newer treatment modalities that target the gut–brain axis and stem cell therapy have proven to induce remission and sustain it [3, 7, 8].

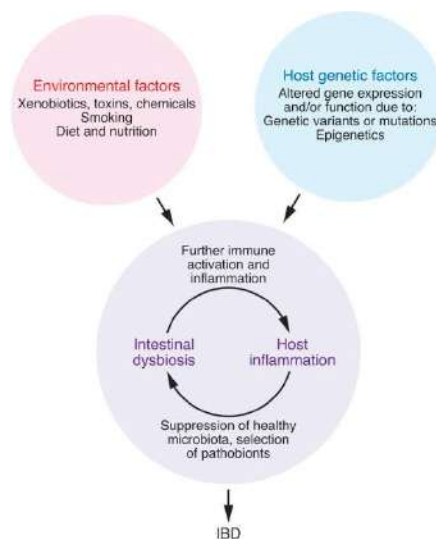


Fig. 1: Etiology

Etiology of Inflammatory Bowel Disease

Inflammatory Bowel Disease, which includes Ulcerative Colitis and Crohn's Disease, has a multifactorial etiology. The exact cause is not fully known, but it results from an inappropriate immune response in genetically susceptible individuals.

1. Genetic Factors

- Family history increases the risk of IBD.
- Multiple susceptibility genes (e.g., NOD2/CARD15, IL23R) are associated, especially in Crohn's disease.
- Higher concordance rates in monozygotic twins.

2. Immune System Dysfunction

- Abnormal and exaggerated immune response against intestinal microbiota.
- Increased production of pro-inflammatory cytokines (TNF- α , IL-1, IL-6).
- Loss of immune tolerance to gut antigens.

3. Environmental Factors

- Diet: High fat, refined sugar, low fiber diets.
- Smoking: Increases risk of Crohn's disease; protective in ulcerative colitis.
- Stress: Triggers disease flares.
- Urbanization and hygiene hypothesis: Reduced early microbial exposure.

4. Intestinal Microbiota Alterations

- Dysbiosis (imbalance between beneficial and harmful bacteria).
- Reduced microbial diversity.
- Increased pathogenic bacteria triggering inflammation.

5. Infectious Factors

- Certain bacterial or viral infections may initiate disease in predisposed individuals.
- Not a direct cause but may act as a trigger.

6. Epithelial Barrier Defects

- Increased intestinal permeability ("leaky gut").
- Impaired mucosal barrier allows antigen penetration and immune activation.

7. Drugs and Lifestyle Factors

- NSAIDs may exacerbate or trigger IBD.
- Oral contraceptives and antibiotics may increase risk.

IBD develops due to a complex interaction between genetic susceptibility, immune dysregulation, environmental triggers and altered gut microbiota, leading to chronic intestinal inflammation ^[9-14].

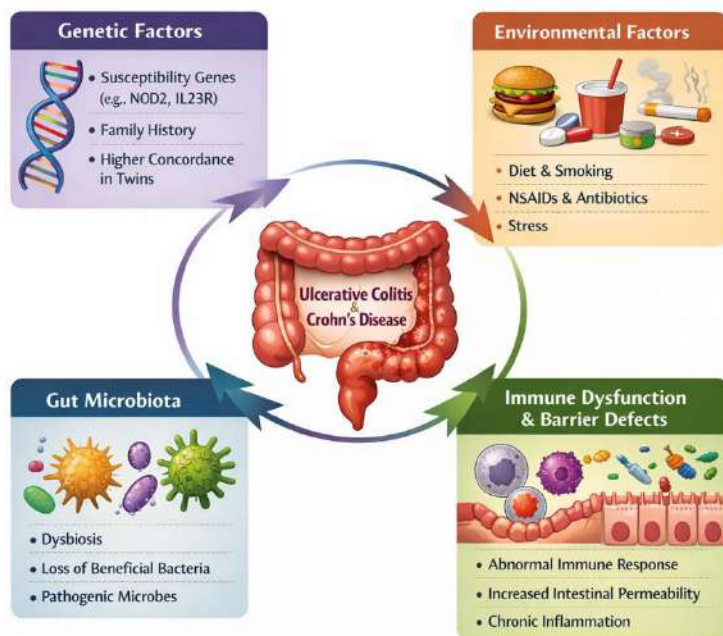


Fig. 2: Etiology of Inflammatory Bowel Disease

Pathogenesis of Inflammatory Bowel Disease

Any long-term inflammatory condition of the gastrointestinal tract (GIT) is referred to as inflammatory bowel disease. This comprises IBD unclassified, Crohn's disease (CD) and ulcerative colitis (UC). According to recent studies, the prevalence and incidence of IBD increased by up to 46% and 169%, respectively, between 2006 and 2021, indicating a significant increase in the burden of IBD globally during the past ten years. IBD has reportedly extended to poor nations during the past 50 years and the incidence rates of pediatric-onset IBD have alarmingly increased. Despite being a manageable diagnosis, it is not uncommon for complications to arise; they can be severe and debilitating to the patient, causing them to experience an array of symptoms, including diarrhea, abdominal pain, fever and weight loss. Moreover, it is essential to consider the financial burden of IBD. As of 2016, the US predicts a \$875 billion cost for IBD patients nationwide.

It is widely acknowledged that the ongoing GIT inflammation is caused by an incorrect immune response to some unidentified trigger, even though the pathophysiology of IBD is poorly understood. Additionally, several data lend credence to the multifactorial approach, which postulates that changes in gut flora, environmental triggers and genetic predisposition interact to cause

IBD. According to a 1988 European study, monozygotic twins with CD and UC had likely concordance rates of 58.3% and 6.3%, respectively. Proband concordance in dizygotic twins, on the other hand, was 3.9% in CD and none in UC. This suggests that IBD has a major genetic component. Although not exhaustive, extensive research in the genetic predisposition of IBD found 242 common susceptibility loci, with NOD2, TNFSF15 and human leukocyte antigen to be the most significant.

The NOD2 gene mutation is the strongest genetic risk locus and is strongly associated with increased *E. coli* in the intestine. NOD2 is an intracellular pattern recognition receptor that identifies muramyl dipeptide, a component of bacterial peptidoglycan, thereby playing a crucial role in the innate immune system's ability to detect and respond to bacterial pathogens. Mutations in NOD2 can impair this recognition, leading to inadequate immune responses and increased susceptibility to intestinal inflammation. Another notable genetic mutation is ATG16L1, a gene that contributes to the lysosomal degradation and clearance of pathogens, better known as the autophagy pathway. Mutations in ATG16L1 can disrupt autophagy, leading to impaired clearance of bacteria and dysfunctional immune responses. This impairment contributes to the persistence of inflammation characteristic of IBD.

The interaction between NOD2 and ATG16L1 is particularly noteworthy. NOD2 can recruit ATG16L1 to the plasma membrane at the bacterial entry site, initiating autophagy in response to bacterial invasion. Mutations in either gene can disrupt this process, leading to defective bacterial handling and increased inflammation.

Intestinal inflammatory episodes are a hallmark of IBD, a persistent and potentially fatal illness. Significant advancements over the past few decades have expanded our knowledge of the pathophysiology of IBD, particularly in the area of immunology and created more chances to investigate alternative treatment pathways and targets. However, there are still unanswered concerns about intestinal inflammatory causes, disease behaviour and aetiology in various subgroups of IBD patients that need to be investigated. In order to gain a thorough understanding of the pathophysiology of IBD, relationships between proinflammatory and anti-inflammatory immune cells and molecules and different genetic susceptibility, intestinal microbiota and environmental factors (such as diet, smoking and physiological stress) are constantly being assessed.

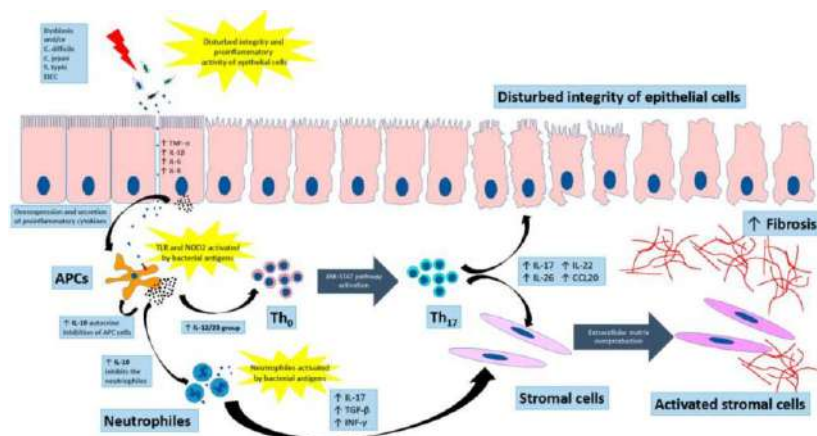


Fig. 3: Pathogenesis of inflammatory bowel diseases (IBDs). The dysbiosis of gut microbiota is a cause of exacerbation of the disease and determines the severity of the mucous inflammation. It causes the imbalance in the integrity of epithelium barrier and promotes infection of, i.e., *C. jejuni*, *S. typhi*, enteroadherent or serotypes enteroinvasive of *E. coli* (EIEC). By stimulating membrane Toll-like receptors (TLR) and intracellular NOD receptors (nucleotide-binding oligomerization domain proteins, NOD1, NOD2) in immune cells, including antigen-presenting ones (APCs), the cytokine pathway of the cellular immune response and tissue secondary remodeling is activated. The important role is played by Th17 lymphocytes derived from naive Th0 lymphocytes under control of IL23 and IL12. The cytokine mediated signal transmission through JAK/STAT pathway ultimately activates Th17 cells, which are the source of several pro-inflammatory cytokines: IL17A, IL17F, IL22, IL26 and the chemokine CCL20. In addition, the IL-10 affects the activity of Th17 lymphocytes inhibition which are donors of IL17, IL23, IL6. As well as the IL10 has the ability to inhibit the APCs by reducing the expression of major histocompatibility complex (MHC) and to control another level of adaptive immune answer. The IL17, IL23, IL6 and TGF- β , INF- γ are involved in the recruitment of neutrophils in inflamed tissue and in the activation of mesenchymal cells that play a major role in fibrosis in IBD.

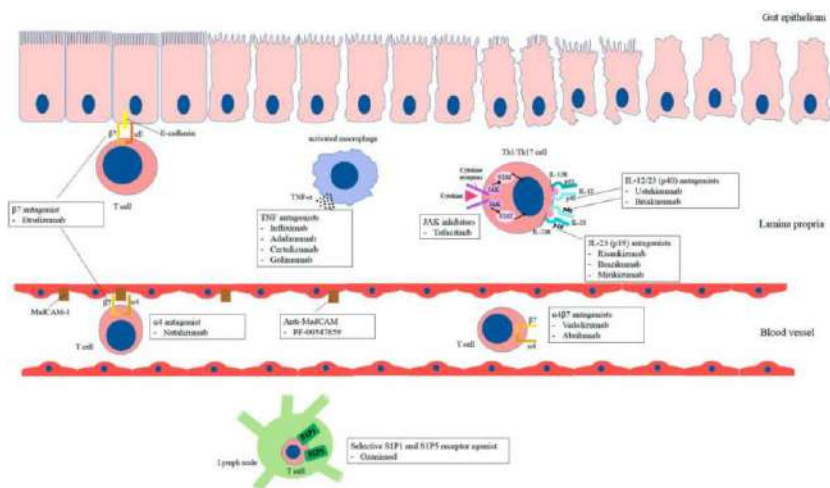


Fig. 4: Effect of biological drugs on the modulation of the immune response in patients with inflammatory bowel diseases. TNF—tumor necrosis factor, JAK—Janus kinase, MadCam-1—Mucosal vascular addressin cell adhesion molecule 1, S1P1—Sphingosine-1-phosphate receptor 1, S1P5—Sphingosine-1-phosphate receptor 5.

According to the World Gastroenterology Organisation (WGO) Practice Guidelines, there are various drug and surgery treatment options for IBD patients, each with a role in a specific phase of pathology. More so for UC than CD, aminosalicylates have been proven to be effective in both inducing remission and a role in maintenance. A notable biological drug is anti-TNF agents, an example being Infliximab, that have demonstrated effectiveness in severe perianal CD and rescue therapy in corticosteroid-refractory severe UC. Vedolizumab, another biological agent, demonstrates effectiveness in inducing and maintaining remission. In more extreme cases, corticosteroids can suppress inflammation and rapidly relieve symptoms.

Antibiotics and probiotics also play a role in treating CD and UC complications. The most used class of drugs is immunomodulators, which consist of thiopurines and methotrexate, both of which are ineffective at inducing remission but are proven to be effective at maintenance. Immunomodulators reduce or eliminate corticosteroid dependence and are the primary choice if aminosalicylates and corticosteroids are ineffective long-term. Calcineurin Inhibitors, another immunomodulator drug, are reserved for acute severe colitis. A range of surgeries are also used in cases of refractory disease and they can be very effective in inducing long-term remission. In CD, ileocecal resection is the primary option, as well as many other surgeries used to correct complications, like drainage of abscesses, bowel-sparing

stricturoplasty and ileorectal or ileocolonic anastomosis. In UC, total proctocolectomy plus permanent ileostomy proved an effective treatment for inducing long-term remission. A summary comparison of the efficacy and mechanisms of different immunomodulatory therapies is represented below in Table 1 & 2 ^[15-30].

Table 1: Immunomodulatory therapies in IBD

Therapy	Mechanism of action	Limitations
Fecal microbiota transplant (FMT)	Restores microbial diversity	Donor variability; safety concerns
Infliximab (anti-TNF)	Neutralizes TNF-alpha	Infection risk; immunogenicity
Stem cell therapy	Immune modulation and tissue repair	High cost; regulatory hurdles
Probiotics	Competitive inhibition of pathogens; anti-inflammatory	Inconsistent efficacy; species-specific effects

Table 2: Novel drugs

Drug	Pathway/mechanism of action	Main issues and side effects
Ustekinumab	IL-12/IL-23	Cardiovascular safety.
Tocilizumab	IL-6R	No further studies since 2004.
Tofacitinib	JAK-1, JAK-2, JAK-3	Increased risk for infections. Alterations in serum lipids observed. Unclear efficacy in CD.
Filgotinib	JAK-1	Increased risk for infections.
Laquinimod	-	Good safety profile. Ongoing long-term trials.
Alicaforsen	ICAM-1	Intravenous formulation ineffective in CD.

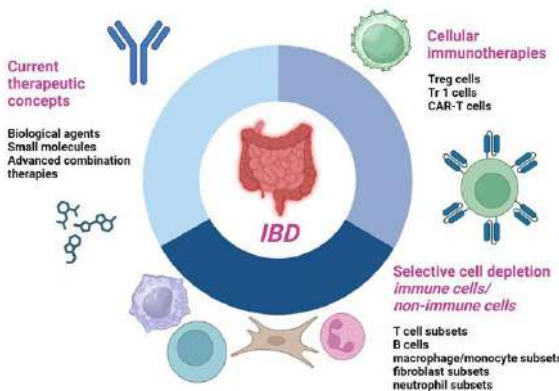


Fig. 5: Current therapies and novel possible cellular and immune- cell depleting therapies for inflammatory bowel disease therapy

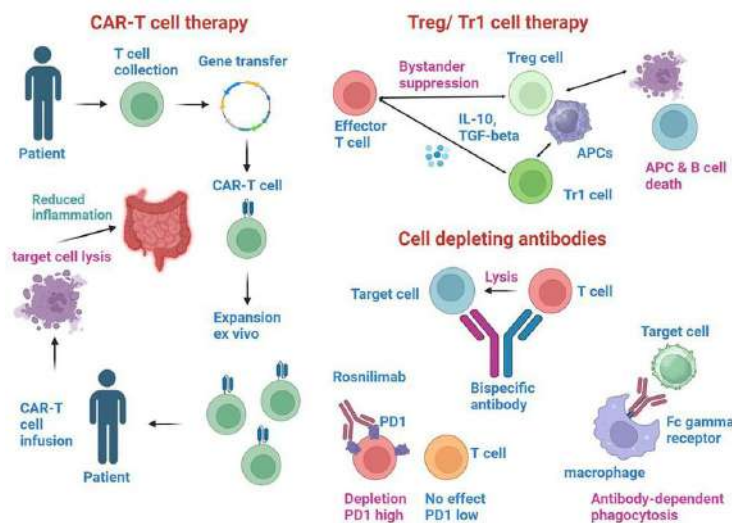


Fig. 6: New approaches for therapy: schematic of CAR- T cell therapy from cell generation to application is shown (left side). Furthermore, the mode of action of T regulatory cells (Treg) and Tr1 cells is shown (upper right side). In addition, cell depleting antibody therapies are shown (lower right side). IL, interleukin; TNF, tumour necrosis factor.

Aminosalicylates

Aminosalicylates for IBD mainly include traditional sulfasalazine (SASP) and other types of 5-aminosalicylic acid (5-ASA) drugs. SASP is composed of 5-ASA and sulphapyridine (SP) by diazo bonding and has been used to treat IBD for 80 years. In the treatment of IBD, SASP is the prodrug, SP is the carrier and 5-ASA is the active part. The mechanisms of action (MOA) of 5-ASA and SASP include interference with the metabolism of arachidonic acid (conversion to prostaglandin and leukin-triene), scavenging of reactive oxygen species and effects on the function of white blood cells and the production of cytokines [31-34].

Calcineurin Inhibitors

Calcineurin, activated by calmodulin, can induce dephosphorylation and activation of the nuclear factor of activated T cells (NFAT). Then the activated NFAT will move from cytoplasm to nucleus and combine with the gene regulatory regions to regulate gene transcription of a variety of inflammatory cytokines [TNF- α , interferon (IFN)- γ , IL-2, etc.]. Calcineurin inhibitors, including Cyclosporine a (CsA) and Tacrolimus (TAC) interfere with the signaling pathway and therefore inhibit the inflammatory response [35-39].

Anti-TNF Therapy

TNF- α is a prototypic member of a large family of cytokines that play important roles in inflammation, apoptosis, proliferation, invasion, etc. Overexpression of TNF- α can cause chronic inflammation and lead to autoimmune diseases and tissue damage. Anti-TNF- α monoclonal antibodies, such as Infliximab (IFX) and Adalimumab (ADA), exert therapeutic effects by inhibiting TNF- α -associated inflammatory responses and tissue damage. IFX therapy may be applied for the treatment of patients who are intolerant or do not respond well to CSs and immunomodulators and are steroid-dependent. A randomized controlled trial evaluating the efficacy of IFX in patients with moderate to severe UC demonstrated that colectomy rates decreased by 7% after 54 weeks of IFX treatment. UC-related hospitalization and surgery rates saw a decrease as well [40-43].

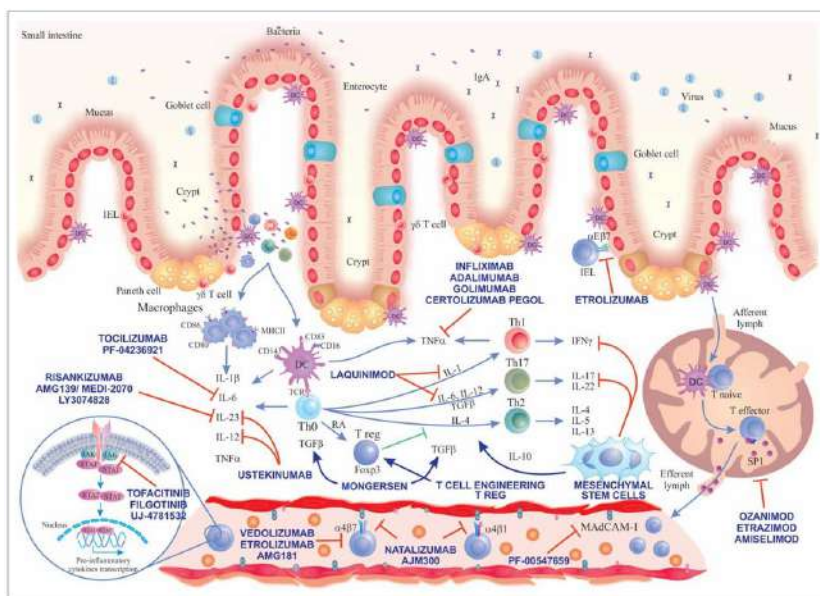


Fig. 7: Immunological pathways targeted by the main novel therapies for IBD. A loss of intestinal barrier integrity takes place in IBD, leading to translocation of bacteria that triggers an exaggerated immune response with secondary activation of Th cell responses (Th1, Th2, Th17). We show the main drugs inhibiting IL-6 pathway, IL-12/23 axis, Jak inhibitors, laquinimod and stimulators of TGF- β 1 pathway (mongersen). Drugs inhibiting TNF- α already approved for use in IBD and cell therapies using MSCs and Tregs and their main immune-modulation functions are depicted in the centre. Substances targeting different adhesion molecules are

described in the blood vessel and in the gut epithelium (etrolizumab). On the bottom right, we show the mechanism of action of drugs reducing the circulating lymphocytes by sequestering them in secondary lymphoid organs (sphingosine-1-phosphate receptor modulators). Main abbreviations: IEL, intraepithelial lymphocyte; DC, dendritic cell; JAK, Janus kinase; STAT, signal transducer and activator of transcription; IL, interleukin; Th, T helper lymphocyte; TGF- β , transforming growth factor-beta; RA, retinoic acid; IFN γ , interferon gamma; S1P, sphingosine-1-phosphate.

Anti-IL-12/23 Therapy

IL-12 and IL-23 are important pro-inflammatory cytokines in intestinal inflammation, mainly produced by antigen-presenting cells. IL-12 is composed of the p35 and p40 subunits and IL-23 is composed of the p40 and p19 subunits. Preclinical studies have suggested that IL-12 and IL-23 are involved in the pathophysiological process of IBD and play a role in the induction and maintenance of intestinal inflammation. In addition, genomic studies have shown an association between the IL-12/IL-23 pathway and CD. Ustekinumab is a fully humanized IgG1 monoclonal antibody that binds to the common p40 subunit of IL-12 and IL-23 to inhibit the binding of IL-12 and IL-23 to the IL-12 receptor on the cell membrane surface of T cells and NK cells, thereby inhibiting intestinal inflammation. Ustekinumab has been approved be effective for the treatment of moderate to severe CD and UC [44-46].

Surgical treatment

Although the introduction of biologics has greatly advanced the pharmacological therapy of IBD, surgery remains a crucial part of the disease's management. The rate of surgery for CD has dropped from 10 to 8.8% ($P < 0.001$) and for UC from 7.7 to 7.5% ($P < 0.001$), despite the rise of hospitalised patients in recent years. The mortality rate for CD patients following non-selective surgery decreased in the age of biologics, while it rose to 15% for UC patients, according to a study in the New York State Database. Surgical and perioperative care can yet be improved.

The absolute indications of operation in UC patients principally include complicated massive bleeding, intestinal perforation, carcinogenesis and highly suspected carcinogenesis. Relative indications include: (1) Patients with severe UC fail to respond to active medical treatment and patients with toxic megacolon have no response to medical treatment, earlier surgical intervention is suggested. (2) The medical treatment effect is poor and/or adverse drug reactions have seriously affected the quality of life. For localized

ileocaecal CD patients who failed to respond or relapse after initial medical therapy or preferred surgery to continued drug therapy, laparoscopic resection is recommended.

Due to the poor long-term outcomes, surgical options for perianal Crohn's fistula can only be offered to a selected group of patients after consultation, especially patients with complex diseases and ongoing disease activity. One study showed that the symptomatic recurrence rate of CD patients was 20% at 1 year and 34% at 3 years after ileocelectomy, while the endoscopic recurrence rate reached 73 and 85%, respectively. Regular post-operative endoscopic examination may help monitor recurrence and develop prevention and treatment plans [46-50].

Apheresis Therapy

Apheresis therapy is a novel treatment for IBD developed in Japan, whose main mechanism is to reduce the local inflammatory response by isolating and absorbing one or more specific leukocytes (such as granulocytes, monocytes and activated lymphocytes) in the peripheral blood. Adsorptive granulocyte/monocyte apheresis (GMA) has been shown to be effective in inducing remission in patients with UC and CD [9,51,52].

Challenges

A major concern during the pandemic has been the safety of continuing immunosuppressive therapies in patients with IBD. These therapies, which include corticosteroids, thiopurines, methotrexate and biologics, are essential for controlling inflammation and maintaining remission in patients with IBD. However, they also suppress the immune system, potentially increasing the risk of infections, including COVID-19.

Early in the pandemic, there was considerable uncertainty about whether patients on immunosuppressive therapies were at increased risk of contracting COVID-19 or experiencing more severe disease. This uncertainty led to difficult decisions for both patients and healthcare providers regarding the continuation, modification or temporary cessation of treatment. In some cases, patients independently chose to discontinue or reduce their medications out of fear, which led to disease flares and complications.

Education and support are essential components of managing IBD during the pandemic. Patients need clear, evidence-based information about the risks and benefits of continuing their treatment, the importance of vaccination. Healthcare providers play a key role in addressing patients' concerns, correcting misinformation and providing reassurance. Telemedicine allows

patients to receive medical consultations, discuss symptoms and adjust treatment plans without the need for in-person visits, thus reducing the risk of exposure to SARS-CoV-2. It has also facilitated more frequent check-ins, enabling healthcare providers to monitor patients more closely during this uncertain time [6, 53-55].

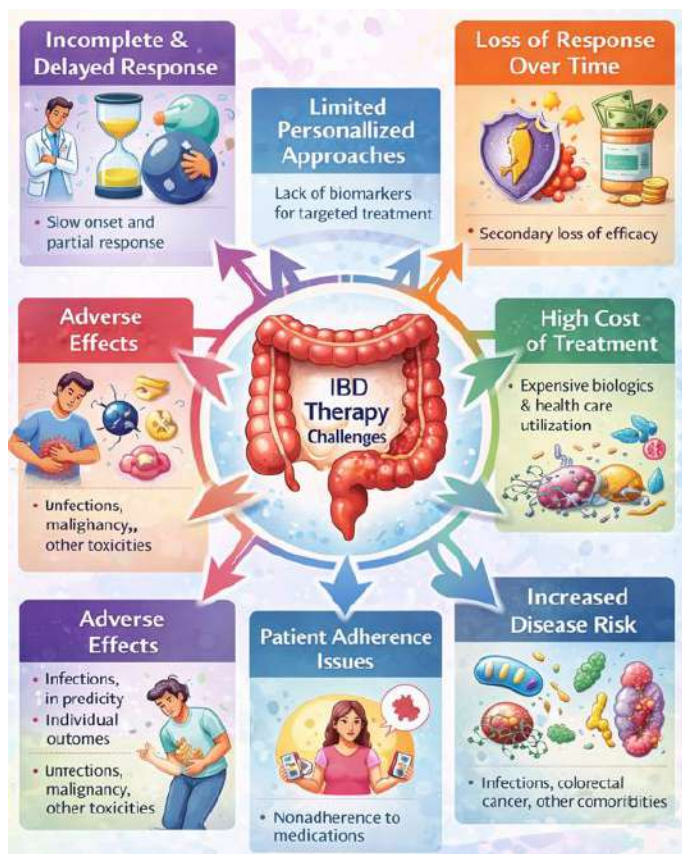


Fig. 8: Challenges

Future perspectives

IBD is a chronic inflammatory disease that affects young people and is becoming more common. Although the etiopathogenesis of IBD is still poorly understood, recent research indicates that the development of new treatment options depends on a better understanding of the immunological pathways involved in IBD pathogenesis. Thiopurines and anti-TNF medications are examples of effective pharmaceutical treatments now utilised in clinical practice. However, some of these medications have serious adverse effects,

such as infections or an elevated risk of certain malignancies and their effectiveness may eventually wane. In fact, up to one third of the patients do not have a satisfactory response to these therapies.

Consequently, the search for new therapeutic strategies targeting alternative immunological pathways has intensified. New therapies targeting alternative pro-inflammatory pathways like IL-12/23 axis, IL-6 pathway or Janus Kinase inhibitors are on its way. Alternatively, some emerging oral substances that aim to stimulate canonical immune-modulating pathways, like the TGF- β pathway, have shown clinical efficacy. The inhibition of adhesion and migration of leukocytes into the inflamed intestinal mucosa has also received much attention. Molecules like vedolizumab are currently approved for IBD and other approaches targeting alternative adhesion or migration mechanisms are in advanced phases in clinical trials. Finally, the possibility of engineering immune-modulating cells like MSCs or Tregs is a promising alternative approach, but cell therapies still need to prove safety and efficacy in larger clinical trials.

In conclusion, several novel treatment strategies for IBD are on their way and will certainly expand our therapeutic armamentarium in the next future. However, IBD is a very heterogeneous disorder where patients have different genetic and environmental backgrounds and can display a wide variety of clinical phenotypes. In addition, IBD treatment is still based basically on clinical and endoscopic findings and patients may have unpredictable responses to different therapies. This makes it difficult for the clinician to choose the appropriate drug according to risk factors and clinical course. A better understanding of the immunopathogenesis of IBD is crucial to help the clinician to select the most appropriate therapeutic approach to maximize cost-efficacy and minimize risks and undesirable side-effects derived from the immune regulation (like infections or the inhibition of other protective properties like epithelial healing). Furthermore, a combination of some of these novel drugs with the ones currently in use could be a plausible strategy to improve therapeutic outcomes by targeting different pathways ^[56-59].

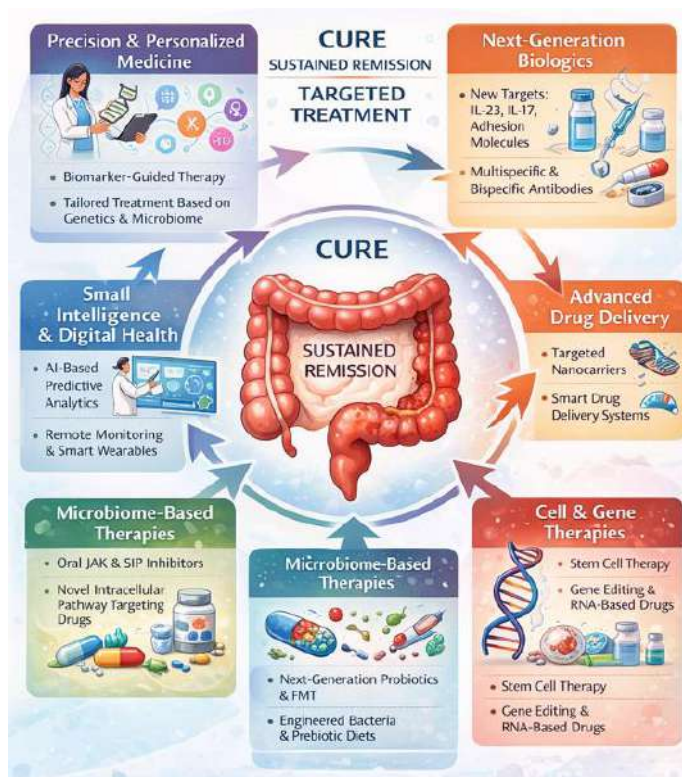


Fig. 9: Future perspectives of Inflammatory Bowel Disease

Conclusion

IBD is a chronic disabling inflammatory process that affects young individuals, with growing incidence. The etiopathogenesis of IBD remains poorly understood, but recent studies show that improved understanding of the immunological mechanisms involved in IBD pathogenesis is key to the development of new therapeutic options. Current pharmacological treatments used in clinical practice like thiopurines or anti-TNF are effective. However, some of these drugs have significant side effects like infections or an increased risk for certain cancers and their efficacy may diminish over time. In fact, up to one third of the patients do not have a satisfactory response to these therapies. There are several therapeutic options for IBD, including agents that induce remission, such as aminosalicylates, corticosteroids and biologics and those that maintain remission, like immunomodulators. Despite the role of surgery in refractory cases, pharmacological interventions remain central due to the high risk of recurrence. Recent advancements have introduced gut-brain axis-targeted therapies, including stem cell treatments, biologics like anti-TNF

agents and integrin antagonists, probiotics and FMT, all aiming to modulate immune responses and restore gut microbiota balance.

Current therapeutic concepts in IBD still carry substantial limitations, with many patients failing multiple lines of therapy with biological agents or small molecules. Despite promising initial data on combination of advanced therapies with simultaneous treatment of several biologicals or small molecules, a significant unmet medical need for innovative and transformative approaches to therapy remains. We have highlighted the mechanisms and potential future clinical relevance of novel cellular and immune cell-depleting strategies for IBD therapy. Novel CAR- T cell approaches, including CD19+ (B cells) and IL-23R- targeting CAR-T cells, have the potential to yield a significant impact in the treatment of patients with refractory IBD. With this knowledge, we may have the ability to develop novel personalized treatments for IBD patients.

In the progress of achieving personalized and precise therapy, there are both opportunities and challenges. Doctors should fully grasp the indications, contraindications, as well as evidence-based medicine of various drugs and treatments, so as to develop individualized treatment plans based on the comprehensive assessment of the patient. The treatment should be flexible and changed according to the patient's response to the treatment. Additionally, self-management and regular follow-up of patients should not be neglected. Although the efficacy and safety of these therapeutic modalities must be established through clinical development programmes, these potential new treatment options may provide insights into the role of effector immune cell subsets and offer a means of breaking through the therapeutic ceiling and overcoming resistance to therapy in IBD patients

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All authors read and approved the final manuscript.

Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

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6 CHAPTER

Artificial Intelligence & Nature Inspired Computing based Strategies for Environmental Sustainability

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1. Introduction

In the 21st Century, Advancement in Technological fields and expanding level of Urbanization has defined the new definition of development which facilitates the need of current generation by compromising the multiple factors including heritage and culture, environment etc. Sustainable Development is a holistic approach aims for progressive development of the current generation in various basic facilities without distressing the ability of future generation to meet its needs and aims to achieve sustainability. Sustainability is defined socially, economically and environmentally interconnected to each other to complement ^[1]. Sustainability will be achieved in the scenario where individual in the community will be included socially and part of the economic growth of the society without compromising the environment health. “Environmental sustainability” defined as the state of balance, resilience and interconnectedness that allows the human community to fulfil its needs neither preventing ecosystem regenerate the services required to meet those needs nor by actions that harm biodiversity ^[2]. Climate Change is one of the challenging issues arouse as result of destructing the environment to satisfy the several requirements. Various environmental issues like Bio-diversity conservation, climate change, Clean Air, Pure Water, Efficient Energy Management, Agriculture, Sanitation & Nature-friendly urban mobility, ^[3] etc. needs to be addressed properly and provided the solutions to achieve Environmental Sustainability.



Fig. 1: Environmental Sustainability

Conventional approaches are engaged towards this goal which requires shifting of the paradigm in present technology-driven time. Artificial Intelligence (AI) and Nature Based Computing (NIC) are one of the effective expertise with the technological framework tend to solve the highly computational and complex task. Artificial Intelligence is one of the fields of computer science that incorporate the human behaviour, intelligence and decision making abilities into the computer machines as “Intelligent & Smart” for performing the task autonomously. AI aims to design and development of machines simulating and integrating the human intelligence [4] and Self-learning capabilities referred as AI-based Model. Various AI techniques i.e. Machine Learning, Deep Learning, Data Mining, Computer Vision are implemented to build AI driven model. Machine learning (ML) tends to solve the high computational task by Self-learning abilities i.e. using past or historical data, used to train and test the model. ML techniques are classified in Supervised, Unsupervised and Enforcement Learning [5]. Deep learning model tries to solve the problem with the help of neural networks. AI contribute a major role to achieve environmental sustainability [6].

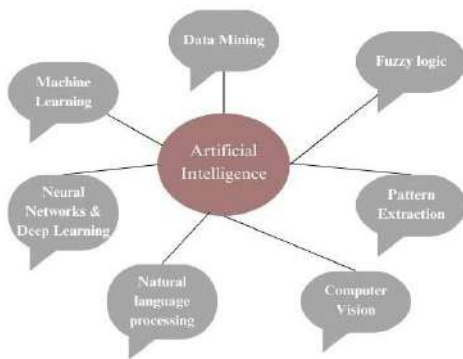


Fig. 2: Artificial Intelligence Expertise

Nature Inspired Computing (NIC) draws the inspiration from nature including biological, ecological and physical phenomenon [7]. NIC simulates the intelligence of animal and species i.e. decisions carried to make activities like movement, searching for food, hunting, survival etc. surrounding us into an algorithm (PSO, ACO, GTO, etc.) to solve the optimization problem. It simulates the biological simulations like genetic programming etc. A few number of nature inspired algorithms is shown in figure 2.

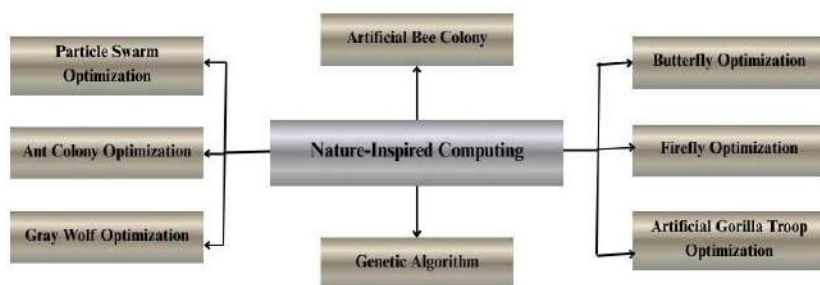


Fig 3: Nature-Inspired Computing

Nature Inspired algorithms play a significant role for environmental sustainability by optimizing the various issues. AI & NIC based various methodologies for Environmental Sustainability has been studied, analyzed and classified for identifying the current advancements for environment protection and exploring the more ideas in future context.

2. Methodology

Information Retrieval (IR) is used as technique to extract the relevant information about the work conducted in this study. Information retrieval is method of obtaining the desired information from the large data set [8]. Boolean Model of IR is implemented to extract the research articles for the proposed work from the large dataset. The dataset of this study contains the papers from Conferences & high standard quality journal like Science Direct, IEEE, Nature, Wiley, ACM, MDPI, Sensors, Taylor & Francis etc. Basic terms of Boolean model i.e. AND, OR & NOT are applied in search engines for fetching of required document from world wide web but not in ranking order like “DEEP AND LEARNING AND MODEL AND FOR AND WATER AND QUALITY AND ASSESSMENT” will fetch all documents containing all the keywords (Highlighted Underline) at the same time.

3. AI & Nature Inspired Algorithms for Environmental Sustainability

To address and searching the effective solutions for environment issues involving the different sectors like Bio-diversity conservation, Climate

change, Water environment, Air pollution monitoring, Efficient energy management, Nature friendly farming and Urban management (Sanitation & Transportation), AI & NIC based various techniques have been discussed in this section.

3.1. Bio-Diversity Conservation

Protection of habitats against illegal hunting, poaching, human-animal conflict along with detection & subsequent prevention of deforestation will be discussed.

3.1.1. Conservation of Animals & Wildlife Species

An AI based Model for threat detection and response system for rare spices has been proposed by Nalayini C.M. *et al.* ^[9] with the objectives of protection of wildlife animals from human threat by alarming the authorities for prior actions. The proposed work integrate YOLOv8 for object detection i.e. identification of poachers along with Histogram of Oriented Gradient technique with firefly algorithm to customize the dataset to train and test the model followed by development of communication platform for alerting the official via SMS. The model is evaluated by prediction speed, accuracy and precision of generated alarms.

Julia Hermann *et al.* ^[10] presented AI-driven model for animal detection using UAV based Thermal images where DJI Matic UAV platform and YOLO is applied for capturing the images by analysing the emitted invisible infrared signals and object detection respectively. YOLO model applies the detection mechanism onto the captured images and put them for mapping and visualization using Open Street Map enabling the different type of views for animal detection.

A Hybrid deep learning model comprises VGG and Bi-LSTM based model is presented by Natarajan B *et al.* ^[11] for minimizing the human-wildlife conflict where movement of wildlife animal along with its type is tracked and subsequently alert messages is generated to inform the official for taking the appropriate actions to prevent the conflict in case of animal approaches near the human society. The proposed work starts with collecting the data from sources like Camera trap, CDnet etc. to train the model for classification of identified animals detected by YOLOR followed by extraction of predicted results and communication for further action. The model is evaluated based on mean accuracy and F1 score.

3.1.2. Deforestation Detection

Deforestation is one of the main reasons for climate change which is

happening for forest land acquisition for agriculture or industrialisation. AI based various techniques for deforestation detection are studied.

Ian McCallum *et al.* ^[12] presented deep learning (DL) based approach for detecting the degradation of Amazon Rainforest. The proposed approach includes satellite images which are provided to community for their classification & labelling as 'Deforestation' or 'No deforestation'. These crowd-sourced images are used to train DL models i.e. VGG16, Res Net 18, ResNet34 and Mobile Net V2 and testing them as well. Author tries to minimize the time between detection of forestation and confirmation of the same.

The model of Deforestation spotting in rural areas covered by Ivory Coast is proposed by Gabriele Sartor *et al.* ^[13] which collects the Optical & Radar data for the given Region of Interest (ROI) to train the deep learning based models U-Net, Attention U-Net, SegNet-ResNet350 and FCN32-VGG16. One of the trained models after testing, is carried out to categorized the data into forest or Non-forest map. Deforestation is carried out pixelwise and will be detected if a forest labelled pixel is converted to Non-forest label. The evaluation metrics for selecting the model is Accuracy, Precision and Recall etc.

3.2. Climate Change

The climate change in present time is unpredictable due to environment mismanagement, increasing level of emissions of pollutants etc. AI powered techniques for weather forecasting along with prediction of natural disaster will be studied.

3.2.1. Weather Forecasting

Weather related data like temperature, humidity, wind etc. is predicted. Numerical Weather prediction (NWP) is quite effective for predicting weather by placing the numerical equations and physics fundamentals.

Remi Lam *et al.* ^[14] presented machine learning based weather prediction (MLWP) based model GraphCast for prediction the weather for next 10 days at 0.25 degree resolution. This model is trained using past data and implemented as "Encoder Processor Decoder" configuration. The proposed model can also be used for cyclone prediction.

FOURCASTNET (Fourier Fore Casting Neural Network) is presented by Jaideep Pathak *et al.* ^[15] for predicting the weather data such as wind speed, extreme temperature in short to medium range at 0.25 degree resolution. This model is based on Adaptive Neural operator and is trained using ERA5 dataset

which comprises an hourly estimate of weather data.

A hybrid deep learning framework integrating Convolutional Neural Network (CNN) and Long Short-term Memory (LSTM) is introduced by Rohan Das *et al.* [16]. This research work gathers the satellite (Geostationary & Polar Orbiting) images along with meteorological data to train the model. Feature extraction of images is performed using texture analysis model. Model is statistically evaluated by computing Mean squared error and Mean Absolute error.

3.2.2. Natural Disaster Warning System

Natural disaster such as earthquake, cyclone or wild forest fire are treated as response to distress the environment. AI driven mechanism are implemented to predict the disaster and discussed.

Md. Abrar Faiaz *et al.* [17] presented disaster warning system with the objective of predicting and generating the guidelines for safety and preparedness to handle the tragedy. It integrates the predictive analytics with large language model (LLM). The proposed model consisting three modules i.e. Disaster prediction, Guidelines generation & Communication module to transmit the generated guidelines (via SMS or Email). Current weather information is used to train the machine learning (CNN, LSTM, SVM) based model for predicting the disaster and LLM is used for guideline generation.

Generative machine learning based diffusion model is implemented by Jingjia Luo *et al.* [18] to forecasting the tropical cyclone. This model is probabilistic in nature as it considers the uncertainty of weather to predict the cyclone. To train the model better, satellite images from TCIR and SHIPS dataset is collected. Model is evaluated based on root mean square error and continuous ranked probability score.

Rohini Bhosale *et al.* [19] introduced deep learning based hybrid model including Change Detection (CD), Long Short Term Memory (LSTM) & Attention Mechanism for forest fire detection applied sequentially along with intensity level of fire for effective implementation for preventing it. Satellite images of particular region from NASA, Sentinel-2 with past record is required dataset to training the model. Change detection is applied for quantify the changes in the images and Attention mechanism enhances the accuracy by assigning higher value to relevant factors.

3.3. Water Resources Sustainability

Sustainable water environment is having a significance role in environmental sustainability where “Pure Water for Everyone” should be

addressed and handled effectively. This requires efficient water management in terms of fulfilling the water demand, ensuring water free from pollutants, water conservation (water harvesting, identification & prevention of leakage in distribution system). AI and Nature Inspired Algorithms have been evolved in this direction and have been studied in this section.

Salah L. Zubaidi *et al.* [20] introduced the hybrid model of Artificial Neural Network (ANN) with Marine Predator Algorithm (MPA) for predicting the water demand considering the various climate factors. This model tries to solve the major issue of satisfy the water demand as non-uniform pattern as it integrates the previous data about water consumption along with meteorological data to train the ANN-MPA model with enhanced accuracy. ANN is ML technique having the learning abilities from feed forward back propagation (FFBP) structure while MPA is nature-inspired algorithm, used for fine tuning the ANN parameters. Co-efficient of Determination & Co-efficient of Efficiency are evaluation metrics used in this work.

The issue of monitoring the water quality is important to have 'Pure Water'. Balraj Singh *et al.* [21] presented soft computing based Water Quality Index (WQI) computation to assess the quality of surface water. Various water samples including input variables like sulphate, pH, chloride, sodium as dataset which are distributed in 70:30 to train and test the models respectively. A hybrid model of ANN-FA(firefly algorithm) is selected after the testing process to compute water quality.

Another research work to assess the water quality is given by Bhagavathi Perumal *et al.* [22] considering the factor of Nonpoint source (NPS) pollution. Author adopted the hybrid model including Long Short Term Memory (LSTM), Gray Wolf Optimization (GWO) and Fish Swarm optimization algorithm to carry out the research work. This model is testified based on the parameters involving Dissolved oxygen, Chemical oxygen demand, $\text{NH}_3\text{-N}$ against the statistical terms Root mean square error.

To prevent the water loss or prevention of Non-revenue water (NRW) through leakage in distribution pipes, AI based leak detection is presented by Rangsarit Vanijjirattikhan *et al.* [23], shifted from conventional approach which involves the measurement of water pressure, pipe diameter etc. for performing the same. ML techniques Support Vector Machine (SVM), Deep Neural Network (DNN) and Convolutional Neural Network is comparatively evaluated. Audio sounds coming from the water pipes is collected as dataset for further processing. The repairing team reaches at the location where sound is recorded and do the corrective actions. After the process, actual result of

sound and input sound is fed into the ML models to train. Evaluation is performed by computing the accuracy, sensitivity and specificity of generated data.

3.4. Air Pollution Control Management

In the fast increasing level of Industrialization & urbanization, air is contaminated by carbon fuel emissions from transport vehicle, industries etc. which has to be controlled by continuously monitoring the air quality level and developing the effective policies for further implementation. AI and NIA based various mechanism has been applied to address this concern.

Hai-Bang Ly *et al.* [24] proposed an AI driven model for monitoring the air quality by predicting the concentration level of air pollutant CO & NO₂ by analysing the data collected from multiple sensors along with the weather data i.e. temperature, relative and absolute humidity. Two hybrid models integrating Adaptive Neuro-fuzzy interface system with Particle Swarm Optimization (PSO) and Adaptive Neuro-fuzzy interface system with Simulated Annealing (SA) are deployed to estimate the concentration of NO₂ and CO during each hour for continuously monitoring of air quality level.

Machine learning (ML) driven model is proposed by A. Samad *et al.* [25] for predicting the air pollution level by predicting the concentration level of air pollutants PM_{2.5}, PM₁₀ and NO₂. Five ML techniques Ridge Regressor, Support Vector Regressor, Random Forest, Extra Trees Regressor, Extreme Gradient Boosting are implemented to model the concentration level based on weather data, traffic information and same pollutant concentration level from neighbouring monitoring station and results are found that last parameter influences the predicting abilities of three pollutants mostly.

M. Rajesh *et al.* [26] conducted research work to air quality assessment in real time with the addition of identification of vulnerable sectors or community using the air quality level and previous health records with the purpose to prioritize their treatment in case of urgency situation. ML techniques Random forest, XGBoost etc. are included in this research work.

3.5. Efficient Energy Management

Efficient use of energy resources along with conservation of energy is essential for future generation as it influences various environmental factors. Nature based algorithms with AI technology is deployed in various research works to address this issue out of them, a few works will be discussed in this part.

Abdulwahab Ali Almazroi *et al.* [27] proposed a hybrid model involving

the two NIA techniques Social Spider Algorithm (SSA) and Strawberry Algorithm (SWA) for efficient use of electricity for home appliance by evaluating the optimal schedule. Author performed schedule optimization by evaluating the fitness function for assessing the quality of output. Performance of optimization function is carried out in MATLAB environment.

Another nature inspired hybrid paradigm is presented by Ibrar Ullah *et al.* [28] for minimizing the energy consumption using optimal schedule with enhancement of user comfort by minimizing the waiting time for appliances to be switched 'ON'. Various renewable energy sources and battery power unit is also added for fulfilling this objective. Fitness function is derived by balancing the minimum energy consumption and maximum end user comfort. Moth flame optimization (MFO) and Genetic algorithm is adopted to pursue this work.

3.6. Agriculture

Agriculture sector contributes a major role in economic growth of any country along with environment health. Intelligent farming is need of present time where smart irrigation system predict the required amount of water for crop to conserve the water resources, land suitability for crop includes soil and weather properties, crop & soil health monitoring all these issues are required for preserving ecosystem. AI & NIC based techniques for effective agriculture are discussed.

Durai Raj Vincent *et al.* [29] introduced supervised learning based technique for land suitability by collecting the various input data i.e. soil properties (soil texture, water content), pH value, carbonates from multiple sensors required for train the AI models. Neural network with Multi-layer perceptron technique is adopted. Author classified the output into 4 categories as More Suitable, Suitable, Moderate Suitable & Not Suitable.

Machine learning based method for smart irrigation system is proposed by Anas H. Blasi *et al.* [30] for predicting the requirement of water for irrigation. Input parameters such as land area, soil properties & weather data are collected and extracted for relevant one by data mining approach knowledge discovery in database (KDD) followed by training the AI model Decision Tree (DT) algorithm. The irrigation system will be functioning automated on the basis of live monitoring of input data.

Wenwen Hu *et al.* [31] introduced the hybrid irrigation system integrating the Random forest algorithm with Dung beetle optimization. Author improved the irrigation system by considering the changes in the environment and integrating the adaptive framework like in case of excessive rainfall, proposed

model advised for stop the irrigation, while in case of drought like situation, increased amount of water supply can be suggested.

A hybrid AI model for monitoring the crop health is proposed by Piyush Kumar Patel *et al.* [32] combines the Graph Neural network (GNN) & Large language model (LLM). The propose model is applied on different types of crops to explore its diversity along with design of platform for enabling the decision making process for crop management. Author also implemented the dynamic framework to manage the adverse conditions. The model is evaluated by determining the Crop health accuracy and F1 score for disease detection.

3.7. Environment Management in Urban Context

Wate management and Environment friendly transportation is major challenge especially in urban areas that impact nature at big cost.

3.7.1. Waste Management

Waste pollution is increasing exponentially in the present data due to several reasons i.e. rapid expansion of urbanization, poor disposal management of waste, demotivated steps towards usage of recyclable product etc. AI driven methods are implemented in this area for time being requirement and studied,

Sylwia Majchrowska *et al.* [33] introduced AI driven model for waste detection and classification. Author deployed two new novel data set i.e. Detect-waste and Classify-waste. Detect-waste contains the waste relevant data of indoor, outdoor and under water locations from multiple source WADE-UI, TrashCan etc. is used as input & train the DL based model EfficientDet-D2 to detect & labelling the waste as 'litter' or 'No litter'. Classify-waste dataset contains the detected images with label 'litter' used as input & train another DL model EfficentNet-B2 for classify the waste into eight categories i.e. bio, glass, metal & plastics, non-recyclable etc. Semi-supervised learning method is used to train the classification model.

Bio-waste management and disposal management using AI model is proposed by S. Balasubramaniam *et al.* [34]. This research work uses the hybrid paradigm involving YOLOv8 & Spatial Pyramid Pooling (SPP) for improving the waste detection accuracy & segregation of waste for preventing the pollution and motivating the recycling. Data is collected using IoT sensor and camera. This model also involves the participation of community by encouraging the accountable disposal practices. Evaluation of model is performed on the basis of waste collection efficiency, segregation accuracy, composting efficiency and public participation rate.

3.7.2. Environment Supported Transportation

Today, with the increasing no. of vehicles on road, traffic congestion become a major issue for environment health because of large no of pollutant such as carbon, fossil fuel emission pollutes the air. AI & NIC based intelligent transportation is required apart from the conventional approaches which are discussed in this section.

Vandana Singh *et al.* [35] proposed NIC based transportation management in which NIA algorithms i.e. PSO, ACO & GA is simulated using SUMO platform to generate the optimized road set by analysing the traffic schedule pattern and stored in cloud platform where it gets updated from the input i.e. any road tragic incident, received from the community or crowd. Fitness function is developed by maximizing the of no. of vehicles that arrive at destination and minimizing the waiting time for vehicle.

NIA based hybrid model for optimizing the traffic is given by Kuldeep Vayadande *et al.* [36] with the objective of minimizing the travel time for smooth flow of traffic. Author developed the interactive web based application program for participating the community to update the road information to enable drivers to take alternate route in prior. Modified San Cat Swarm Optimization (MSCSO) algorithm with PSO based fuzzy logic is applied technique in this work. Fitness function for traffic optimization is derived by maximizing the public transport usage & traffic signal compliance and minimizing the parking usage.

4. Comparative Outline of AI & NIC Techniques For Environmental Sustainability

Artificial Intelligence and Nature Inspired computing based various techniques in various sectors of environmental sustainability, studied in Section 3 and is summarized comparatively in this section.

Table 1: Comparative Summary of AI & NIC techniques for Environmental Sustainability

Area	Sub-area	Reference	Methodology/ Model	Paradigm	Findings
Bio-diversity Conservation	Animals and Wildlife Species Protection	[9]	YOLOv8, HOG, Firefly Algorithm (FA)	Original	Identification of poachers as threat for rare spices along with alarming the official
		[10]	YOLO	Original	Monitoring of Wildlife Animals
		[11]	VGG, Bi-LSTM	Hybrid	Monitoring the movement of wildlife animals & alerting the authorities in case of animal approaching near

					the human to prevent human-wildlife conflict
	Deforestation Detection	[12]	VGG16, ResNet18, ResNet34, MobileNetV2	Original	Prediction of deforestation using crowd sourcing decisions
		[13]	U-Net, Attention U-Net, SegNet-ResNet350, FCN32-VGG16	Original	Deforestation detection by classify the images as forest or No forest pixelwise
Climate Change	Weather Forecasting	[14]	GraphCast	Original	Predicting the weather for next 10 days
		[15]	FourCastNet/ Adaptive Fourier Neural Operator	Original	Predicting the weather for short to medium range
		[16]	CNN, LSTM	Hybrid	Satellite images & weather data is used to detecting the weather pattern
	Natural Disaster Alarming System	[17]	Predictive Analytics (CNN, LSTM, SVM), Large Language Model	Hybrid	Disaster prediction along with preventive guidelines
		[18]	Generative AI based Diffusion Model	Original	Probabilistic Prediction of Tropical cyclone
		[19]	Change Detection, LSTM, Attention	Hybrid	Forest fire prediction & alerting system
Water Resource Sustainability	-	[20]	ANN, Marine Predator Algorithm (MPA)	Hybrid	Predicting the water demand considering the weather data
		[21]	ANN, FA, Gaussian	Hybrid	Assessing the water quality i.e. WQI
		[22]	LSTM, GWO, Fish Swarm optimization	Hybrid	Prediction of water quality in the presence of NPS pollution
		[23]	SVM, CNN	Original	Prediction of leakage in water distribution pipes
Air Pollution Monitoring Management	-	[24]	Adaptive Neuro-fuzzy interface system & PSO, Adaptive Neuro-fuzzy interface system & SA,	Hybrid	Monitoring the air quality by predicting the NO ₂ & CO contamination
		[25]	Ridge Regressor, Support Vector Regressor, Random Forest,	Original	Monitoring the air quality by predicting the contamination level of pollutant PM _{2.5} , PM ₁₀ , NO ₂ by varying different parameter
		[26]	Random Forest, Gradient Boosting, XGBoost	Original	Predicting the air pollution level and assessment of vulnerable zone by mapping the air pollution and health records
		[27]	Social Spider Algorithm (SSA), Strawberry	Hybrid	Optimum energy consumption by smart scheduling of home

			Algorithm (SWA)		appliances
Efficient Energy Management	-	[28]	Moth flame Optimization (MFO), Genetic Algorithm	Hybrid	Minimum energy consumption by ensuring maximum of end user comfort by minimizing the waiting time for appliance to be switched ON & renewable energy
Agriculture	-	[29]	Supervised learning based Neural network, Multilayer perceptron	Original	Detection of land suitability for farming and classify as More suitable, Suitable, Moderate Suitable & Not Suitable
		[30]	Decision Tree, KDD	Original	Intelligent irrigation system with dynamic framework
		[31]	Random Forest, Dung Beetle optimization	Hybrid	Irrigation system with abilities to adapt with environmental changes
		[32]	Graph Neural Network, LLM	Hybrid	Crop health prediction for different types of crops under adverse conditions
Environment Management in Urban context	Waste Management	[33]	EfficientDet-D2, EfficientNet-B2	Original, Sequentially Applied	Waste detection & Classification of detected waste into different categories
		[34]	YOLOv8, Spatial Pyramid pooling	Hybrid	Bio-waste detection & segregation of waste for proper disposal & recycling
	Green Transportation	[35]	Various NIC algorithm (PSO,ACO,GA)	Original	Minimize the journey time by involving the community source data about traffic updation
		[36]	Modified Sand Cat Swarm Optimization, PSO	Hybrid	Travelling time is minimized by enhancing the public transport usage & reducing the parking usage parameter

5. Discussion & Conclusion

Environmental Sustainability is one of the pillars for sustainable development. Development is nothing without balancing the natural ecosystem and preserving the environmental health. With the advancement in technologies, traditional approaches is being shifted to digital gradually. In the world of AI, there is requirement of upgrading the environment management and sustaining the bio-diversity system. AI & NIC based various techniques to achieve sustainability has been studied and comparatively analyzed based on some criteria.

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7 CHAPTER

प्रेमचन्द के साहित्य पर गांधीजी के विचारों का प्रभाव : एक अध्ययन

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सार:

भारतीय साहित्य के प्रमुख युगपुरुष मुंशी प्रेमचन्द की रचनाएँ राजनीतिक तथा सामाजिक चेतना की गहरी अभिव्यक्ति हैं। प्रस्तुत शोध का उद्देश्य महात्मा गांधी के विचारों तथा स्वतंत्रता आंदोलन का प्रेमचन्द के साहित्य पर प्रभाव का विश्लेषण करना है। प्रस्तुत अध्ययन यह दर्शाता है कि सत्य, अहिंसा, राष्ट्रभक्ति, सामाजिक न्याय, शोषित-वंचित वर्गों के कल्याण और राष्ट्रीय एकता जैसे गांधीवादी सिद्धांतों से प्रेमचन्द की साहित्यिक दृष्टि प्रभावित रही हैं। विशेष रूप से किसानों, निर्धनों, दलित वर्गों तथा मजदूरों के प्रति उनकी संवेदनशीलता गांधीजी के आदर्शों के अनुरूप नज़र आती है। असहकार आंदोलन तथा स्वतंत्रता संग्राम के दौरान गांधीजी के नेतृत्व ने प्रेमचन्द को साहित्य को राष्ट्रीय आंदोलन का सशक्त माध्यम बनाने हेतु प्रेरित किया। प्रेमचन्द की 'सोज़-ए-वतन', 'कातिल', 'दो बैल', 'दूध का दाम' एवं 'कफ़न' जैसी चयनित कृतियों के विश्लेषण से यह स्पष्ट होता है कि प्रेमचन्द ने गांधीवादी विचारधारा को साहित्यिक रूप देकर छुआछूत, औपनिवेशिक शोषण, सांप्रदायिक विभाजन एवं सामाजिक असमानता के विरुद्ध प्रभावशाली प्रतिरोध प्रस्तुत किया। उनके साहित्य में राष्ट्रीय एकता तथा राष्ट्रप्रेम की भावना भी प्रमुख रूप से अभिव्यक्त हुई है। निष्कर्षतः यह कहा जा सकता है कि गांधीजी ने कर्म तथा विचार के माध्यम से राष्ट्रीय चेतना का निर्माण किया, जबकि प्रेमचन्द ने साहित्य के माध्यम से उसे जन-जन तक पहुँचाया। इस प्रकार, प्रेमचन्द का साहित्य गांधीवादी प्रभाव से प्रेरित होकर भारतीय समाज को नैतिक, सामाजिक एवं राष्ट्रीय दृष्टि से एकीकृत करने में महत्वपूर्ण योगदान देता है।

कुंजी शब्द: मुंशी प्रेमचंद, महात्मा गांधी, गांधीवाद, स्वतंत्रता आंदोलन।

परिचय:

साहित्य मनोरंजन का साधन मात्र नहीं होता, बल्कि वह समाज की आकांक्षाओं, संघर्ष एवं चेतना का सशक्त माध्यम होता है। प्रत्येक युग का साहित्य अपने समय की नैतिक, राजनीतिक एवं सामाजिक परिस्थितियों का जीवंत प्रतिबिंब प्रस्तुत करता है। भारतीय साहित्य परंपरा में कई ऐसे साहित्यकार हुए हैं जिन्होंने अपने लेखन के माध्यम से समाज को दिशा देने का कार्य किया, जिनमें मुंशी प्रेमचन्द का स्थान अत्यंत महत्वपूर्ण है। प्रेमचन्द ऐसे यथार्थवादी साहित्यकार थे जिनकी रचनाएँ भारतीय समाज के वंचित, शोषित एवं उपेक्षित वर्गों की पीड़ा और संघर्ष को मुखर रूप से अभिव्यक्त करती हैं। बीसवीं शताब्दी के प्रारंभिक दशकों में भारत सामाजिक विषमता, औपनिवेशिक शासन, राजनीतिक अस्थिरता तथा आर्थिक शोषण का सामना कर रहा था। इसी काल में महात्मा गांधी भारतीय स्वतंत्रता आंदोलन के केंद्रीय नेतृत्वकर्ता के रूप में उभरे। गांधीजी ने अहिंसा, सत्य, असहयोग, स्वदेशी, सामाजिक समानता एवं राष्ट्रीय एकता जैसे मूल्यों के माध्यम से न सिर्फ स्वतंत्रता आंदोलन को नई दिशा दी, बल्कि भारतीय समाज के नैतिक पुनर्निर्माण का भी प्रयास किया। उनके विचारों का प्रभाव राजनीतिक क्षेत्र तक सीमित न रहकर साहित्य, संस्कृति तथा सामाजिक जीवन तक विस्तृत हुआ। महात्मा गांधी के विचारों से मुंशी प्रेमचन्द का साहित्य गहराई से प्रभावित दिखाई देता है। गांधीजी के नेतृत्व में चले असहकार आंदोलन एवं स्वतंत्रता संग्राम ने प्रेमचन्द को वैचारिक रूप से प्रेरित किया, जिसके परिणामस्वरूप उन्होंने सरकारी सेवा का त्याग कर साहित्य को राष्ट्रसेवा का सशक्त माध्यम बनाया। प्रेमचन्द की कहानियों तथा उपन्यासों में सामाजिक न्याय, राष्ट्रभक्ति, छुआछूत का विरोध, साम्प्रदायिक सद्भाव एवं राष्ट्रीय एकता जैसे गांधीवादी आदर्श स्पष्ट रूप से परिलक्षित होते हैं। प्रस्तुत शोधपत्र का उद्देश्य प्रेमचन्द के साहित्य में विद्यमान गांधीवादी प्रभावों का विश्लेषण करना और प्रेमचन्द ने अपने साहित्य के माध्यम से महात्मा गांधी के विचारों को किस प्रकार जनसामान्य तक पहुँचाया यह स्पष्ट करना है। प्रस्तुत अध्ययन साहित्य तथा स्वतंत्रता आंदोलन के पारस्परिक संबंध को समझने में सहायक सिद्ध होता है और यह प्रमाणित करता है कि साहित्य सामाजिक परिवर्तन एवं राष्ट्रीय चेतना के निर्माण में महत्वपूर्ण भूमिका निभाता है।

समस्या विवरण:

मुंशी प्रेमचन्द का साहित्य स्वतंत्रता आंदोलन, सामाजिक सुधार तथा भारतीय समाज का एक सशक्त दस्तावेज है, लेकिन उनके साहित्य में महात्मा गांधी के विचारों एवं गांधीवादी दर्शन के प्रभाव का सुव्यवस्थित और सम्यक अध्ययन अपेक्षाकृत सीमित रहा है। प्रायः प्रेमचन्द को सिर्फ यथार्थवादी साहित्यकार के रूप में देखा और प्रस्तुत किया गया है, जबकि उनके लेखन में निहित सामाजिक न्याय, अहिंसा, राष्ट्रभक्ति, राष्ट्रीय एकता, छुआछूत का विरोध और शोषित-

वंचित वर्गों के प्रति संवेदना जैसे गांधीवादी मूल्यों पर पर्याप्त ध्यान नहीं दिया गया है। इसके इलावा यह भी एक महत्वपूर्ण शोध-समस्या है कि प्रेमचन्द के साहित्य तथा स्वतंत्रता आंदोलन के पारस्परिक संबंध को समग्र दृष्टि से नहीं समझा गया है। यह स्पष्ट करना ज़रूरी है कि किस प्रकार गांधीजी के नेतृत्व में चले आंदोलनों ने प्रेमचन्द की वैचारिक चेतना को प्रभावित किया और कैसे प्रेमचन्द ने साहित्य को राष्ट्रीय जागरण तथा सामाजिक सुधार का माध्यम बनाया। अतः प्रस्तुत शोधपत्र प्रेमचन्द के साहित्य में विद्यमान गांधीवादी प्रभावों की पहचान, व्याख्या एवं मूल्यांकन की आवश्यकता को रेखांकित करता है।

शोध के उद्देश्य:

प्रस्तुत शोधपत्र के प्रमुख उद्देश्य निम्नलिखित हैं:

1. मुंशी प्रेमचन्द के साहित्य पर महात्मा गांधी के विचारों एवं गांधीवादी दर्शन के प्रभाव का अध्ययन करना।
2. प्रेमचन्द तथा गांधीजी के वैचारिक साम्य को राजनीतिक, सामाजिक तथा नैतिक संदर्भों में स्पष्ट करना।
3. प्रेमचन्द की कहानियों एवं कृतियों में राष्ट्रीय एकता, राष्ट्रभक्ति तथा स्वतंत्रता आंदोलन की अभिव्यक्ति का विश्लेषण करना।
4. प्रेमचन्द के साहित्य में सामाजिक विषमता, छुआछूत तथा शोषण के खिलाफ उठाई गई आवाज़ को गांधीवादी दृष्टिकोण से समझना।
5. यह प्रतिपादित करना कि प्रेमचन्द ने साहित्य को सामाजिक परिवर्तन तथा राष्ट्रीय चेतना के निर्माण का प्रभावी माध्यम बनाया।

शोध पद्धति:

प्रस्तुत शोधपत्र में गुणात्मक तथा विश्लेषणात्मक शोध-पद्धति को अपनाया गया है। प्रस्तुत अध्ययन मुख्यतः वर्णनात्मक, व्याख्यात्मक और तुलनात्मक पद्धति पर आधारित है, जिसके माध्यम से मुंशी प्रेमचन्द के साहित्य में महात्मा गांधी के विचारों एवं गांधीवादी दर्शन के प्रभाव का सम्यक विश्लेषण किया गया है। शोध हेतु प्राथमिक तथा द्वितीयक दोनों प्रकार के स्रोतों का उपयोग किया गया है। प्राथमिक स्रोतों के अंतर्गत मुंशी प्रेमचन्द की चयनित कहानियाँ, उपन्यास, कथा-संग्रह सोज़-ए-वतन और उनके पत्र तथा आत्मकथात्मक लेखन को शामिल किया गया है। द्वितीयक स्रोतों के रूप में गांधीजी के विचारों पर आधारित ग्रंथों, प्रेमचन्द-सम्बंधी आलोचनात्मक पुस्तकों, शोध-लेखों, पत्र-पत्रिकाओं तथा विद्वानों के मतों का अध्ययन किया

गया है। शोध-प्रक्रिया में प्रेमचन्द की रचनाओं का पाठ-विश्लेषण किया गया है और उनमें अभिव्यक्त विषयवस्तु जैसे राष्ट्रीय एकता, राष्ट्रभक्ति, सामाजिक न्याय, अहिंसा, छुआछूत का विरोध तथा शोषित-वंचित वर्गों के प्रति संवेदना को गांधीवादी दृष्टिकोण के संदर्भ में व्याख्यायित किया गया है। इसके साथ ही स्वतंत्रता आंदोलन के ऐतिहासिक एवं सामाजिक परिप्रेक्ष्य को ध्यान में रखते हुए साहित्य तथा राजनीति के पारस्परिक संबंधों का विश्लेषण किया गया है। प्रस्तुत शोध में तथ्यों की प्रामाणिकता बनाए रखने हेतु संदर्भ-ग्रंथों का समुचित उपयोग किया गया है तथा निष्कर्षों को तर्कसंगत एवं वस्तुनिष्ठ आधार पर प्रस्तुत किया गया है। इस प्रकार प्रस्तुत शोध-पद्धति प्रेमचन्द के साहित्य में गांधीवादी प्रभावों की स्पष्ट, संतुलित एवं वैज्ञानिक विवेचना में सहायक सिद्ध होती है।

प्रस्तुत शोधपत्र का योगदान:

1. प्रस्तुत शोध-पत्र मुंशी प्रेमचन्द के साहित्य के अध्ययन में एक महत्वपूर्ण अकादमिक योगदान प्रस्तुत करता है। प्रस्तुत शोध प्रेमचन्द के साहित्य को मात्र यथार्थवादी अथवा सामाजिक दृष्टिकोण तक सीमित न रखते हुए उसमें निहित गांधीवादी विचारधारा को केंद्र में लाकर विश्लेषित करता है। इस प्रकार प्रस्तुत अध्ययन साहित्य एवं स्वतंत्रता आंदोलन के पारस्परिक संबंध को स्पष्ट करने में सहायक सिद्ध होता है।
2. प्रस्तुत शोध-पत्र यह स्थापित करता है कि महात्मा गांधी के अहिंसा, सत्य, सामाजिक न्याय, राष्ट्रभक्ति तथा राष्ट्रीय एकता जैसे विचारों का प्रभाव प्रेमचन्द की रचनाओं में विषयवस्तु, चरित्र-निर्माण एवं नैतिक दृष्टि के स्तर पर व्यापक रूप से विद्यमान है। प्रेमचन्द की कहानियों तथा उपन्यासों के माध्यम से गांधीवादी दर्शन किस प्रकार जनसामान्य की चेतना का हिस्सा बना, इस तथ्य को प्रस्तुत अध्ययन साहित्यिक प्रमाणों के साथ प्रस्तुत करता है।
3. प्रस्तुत शोध छुआछूत, सामाजिक शोषण, सांप्रदायिक विभाजन तथा आर्थिक विषमता जैसे मुद्दों पर प्रेमचन्द की साहित्यिक भूमिका को नए दृष्टिकोण से समझने का अवसर प्रदान करने के साथ-साथ प्रस्तुत अध्ययन यह भी स्पष्ट करता है कि प्रेमचन्द ने साहित्य को राष्ट्रीय आंदोलन एवं सामाजिक सुधार का प्रभावी साधन बनाया।
4. अंततः प्रस्तुत शोधपत्र स्वतंत्रता आंदोलन, हिंदी साहित्य तथा गांधीवाद पर कार्य कर रहे शोधार्थियों हेतु एक उपयोगी संदर्भ-सामग्री सिद्ध होता है और साहित्य के सामाजिक उत्तरदायित्व तथा परिवर्तनकारी भूमिका को समझने में महत्वपूर्ण योगदान देता है।

विश्लेषण एवं विवेचन:

अब तक कई विद्वानों द्वारा मुंशी प्रेमचन्द तथा उनके साहित्य पर गंभीर अध्ययन किया गया है। आलोचकों द्वारा प्रेमचन्द को सामाजिक चेतना का संवाहक, शोषित वर्गों का प्रवक्ता तथा यथार्थवादी साहित्य का प्रवर्तक माना है। प्रेमचन्द संबंधी आलोचनात्मक साहित्य में उनके कथानक-विन्यास, चरित्र-निर्माण, सामाजिक दृष्टिकोण और भाषा-शैली पर विशेष रूप से विचार किया गया है। डॉ. कमर रईस ने प्रेमचन्द के साहित्य को उनके युग के सामूहिक जीवन से जोड़ते हुए यह स्पष्ट किया है कि, 'प्रेमचन्द ने सामाजिक एवं राजनीतिक समस्याओं को गांधीवादी दृष्टिकोण से देखा।' उनके अनुसार, '१९२८ तक प्रेमचन्द पर महात्मा गांधी का स्पष्ट वैचारिक प्रभाव दृष्टिगोचर होता है।' डॉ. सैयद अफ़ील एवं दया नारायण नसीम जैसे विद्वानों ने प्रेमचन्द की कहानियों में सामाजिक सुधार, मानवीय मूल्यों की भूमिका तथा राष्ट्रीय चेतना को रेखांकित किया है। गांधीवादी विचारधारा पर केंद्रित अध्ययनों में यह स्वीकार किया गया है कि गांधीजी के विचारों का प्रभाव साहित्य, पत्रकारिता तथा सामाजिक आंदोलनों तक विस्तृत था। तथापि, प्रेमचन्द के साहित्य में गांधीवादी तत्वों का समग्र एवं केंद्रित विश्लेषण अपेक्षाकृत कम देखने को मिलता है। अधिकांश अध्ययनों में प्रेमचन्द को सामाजिक यथार्थ के लेखक के रूप में देखा गया है, परंतु उनके साहित्य में निहित अहिंसा, सामाजिक समानता, गांधीवादी राष्ट्रीय चेतना तथा एकता के विचारों पर सीमित ध्यान दिया गया है। अतः प्रस्तुत शोधपत्र पूर्ववर्ती अध्ययनों को आधार बनाते हुए प्रेमचन्द के साहित्य में गांधीवादी प्रभावों का समग्र, विश्लेषणात्मक और विवेचनात्मक अध्ययन प्रस्तुत करने का प्रयास करता है।

1. मुंशी प्रेमचन्द के साहित्य का गहन अध्ययन करने पर यह स्पष्ट होता है कि उनकी रचनाएँ मात्र सामाजिक यथार्थ का चित्रण नहीं करतीं, बल्कि उनमें महात्मा गांधी के विचारों की सशक्त प्रतिध्वनि भी सुनाई देती है। गांधीजी के नेतृत्व में चले स्वतंत्रता आंदोलन ने प्रेमचन्द की वैचारिक चेतना को गहराई से प्रभावित किया, जिसके परिणामस्वरूप उनके साहित्य में राष्ट्रभक्ति, सामाजिक न्याय तथा नैतिक मूल्यों को विशेष महत्व प्राप्त हुआ।
2. गांधीवादी अहिंसा तथा नैतिकता का प्रभाव प्रेमचन्द की कहानियों में स्पष्ट रूप से दृष्टिगोचर होता है। कातिल जैसी कहानी में अहिंसा के सिद्धांत एवं उसके सकारात्मक परिणामों को प्रभावशाली ढंग से प्रस्तुत किया गया है। इसी प्रकार दो बैल में हीरा और मोती की एकता प्रतीकात्मक रूप से राष्ट्रीय एकता तथा सामूहिक संघर्ष का संदेश देती है, जो गांधीजी के एकता-संबंधी विचारों से प्रत्यक्ष रूप से जुड़ा हुआ है।

3. छुआछूत तथा सामाजिक विषमता के विरुद्ध गांधीजी के संघर्ष का प्रभाव प्रेमचन्द की कहानियों दूध का दाम और कफ़न में स्पष्ट दिखाई देता है। इन रचनाओं में प्रेमचन्द ने दलित तथा वंचित वर्गों की अमानवीय परिस्थितियों को यथार्थवादी दृष्टि से प्रस्तुत कर समाज की नैतिक चेतना को झकझोरने का प्रयास किया है। यह दृष्टिकोण गांधीवादी सामाजिक समानता एवं मानवीय गरिमा के सिद्धांत से गहरे रूप में जुड़ा हुआ है।
4. राष्ट्रभक्ति और स्वतंत्रता आंदोलन की भावना प्रेमचन्द के कथा-संग्रह सोज़-ए-वतन में विशेष रूप से अभिव्यक्त होती है। इन कहानियों में मातृभूमि के प्रति त्याग, बलिदान तथा समर्पण की भावना गांधीजी के राष्ट्रवादी विचारों की साहित्यिक अभिव्यक्ति प्रतीत होती है। प्रेमचन्द ने तलवार के स्थान पर कलम को संघर्ष का माध्यम बनाकर राष्ट्रीय आंदोलन में सक्रिय भागीदारी निभाई।

इस प्रकार उपरोक्त विश्लेषण से यह स्पष्ट होता है कि प्रेमचन्द का साहित्य गांधीवादी विचारधारा से प्रेरित होकर राष्ट्रीय एकता, सामाजिक सुधार तथा नैतिक पुनर्निर्माण का माध्यम बनता है। उनकी रचनाएँ न सिर्फ स्वतंत्रता आंदोलन के ऐतिहासिक संदर्भ को प्रस्तुत करती हैं, बल्कि आज भी सामाजिक चेतना एवं मानवीय मूल्यों की प्रासंगिकता को रेखांकित करती हैं।

भविष्य की संभावनाएँ:

1. प्रेमचन्द तथा उनके समकालीन अन्य साहित्यकारों (जैसे राजेंद्र लोधा, मंटो, चंद्रशेखर आदि) के गांधीवादी प्रभावों का तुलनात्मक अध्ययन किया जा सकता है।
2. स्वतंत्रता आंदोलन एवं गांधीवाद के विभिन्न साहित्यिक रूपों पर शोध करके समाज तथा राजनीति के बीच साहित्यिक संवाद को और गहराई से समझा जा सकता है।
3. प्रेमचन्द के गांधीवादी विचारों तथा उनकी कहानियों को पाठ्यक्रम और शैक्षिक अध्ययन में शामिल कर युवा पीढ़ी में सामाजिक एवं राष्ट्रीय चेतना को प्रोत्साहित किया जा सकता है।
4. प्रेमचन्द की रचनाओं का डिजिटल रूपांतरण तथा बहुभाषी विश्लेषण करके व्यापक स्तर पर शोध एवं सामाजिक जागरूकता बढ़ाई जा सकती है।
5. भविष्य के शोध में यह अध्ययन किया जा सकता है कि प्रेमचन्द के साहित्य में निहित गांधीवादी, नैतिक एवं सामाजिक मूल्य वर्तमान समाज में किस प्रकार प्रासंगिक हैं और उनका आधुनिक संदर्भ में उपयोग कैसे किया जा सकता है।

निष्कर्ष एवं उपसंहार:

प्रस्तुत शोधपत्र के अध्ययन तथा विश्लेषण से यह स्पष्ट निष्कर्ष निकलता है कि मुंशी प्रेमचन्द के साहित्य पर महात्मा गांधी के विचारों तथा गांधीवादी दर्शन का गहरा और व्यापक प्रभाव रहा है। प्रेमचन्द की रचनाएँ सिर्फ साहित्यिक कृतियाँ नहीं हैं, बल्कि वे अपने समय के राजनीतिक, सामाजिक और नैतिक संघर्षों का सशक्त दस्तावेज भी हैं। गांधीजी के नेतृत्व में चले स्वतंत्रता आंदोलन ने प्रेमचन्द की वैचारिक चेतना को दिशा प्रदान की, जिसके परिणामस्वरूप उनका साहित्य राष्ट्र सेवा तथा सामाजिक सुधार का माध्यम बन गया। प्रस्तुत शोध से यह प्रमाणित होता है कि गांधीवादी मूल्यों जैसे सत्य, अहिंसा, राष्ट्रभक्ति, सामाजिक न्याय, छुआछूत का विरोध एवं राष्ट्रीय एकता को प्रेमचन्द ने अपनी कहानियों और उपन्यासों में प्रभावशाली साहित्यिक अभिव्यक्ति प्रदान की। सोज़-ए-वतन, कातिल, दो बैल, दूध का दाम एवं कफ़न जैसी रचनाएँ यह दर्शाती हैं कि प्रेमचन्द ने शोषित-वंचित वर्गों की पीड़ा को न केवल समझा, बल्कि उसे समाज की सामूहिक चेतना का हिस्सा भी बनाया। उपसंहारतः यह कहा जा सकता है कि जहाँ महात्मा गांधी ने अपने कर्म, नेतृत्व तथा विचारों के माध्यम से भारतीय स्वतंत्रता आंदोलन को सशक्त किया, वहीं मुंशी प्रेमचन्द ने साहित्य के माध्यम से उसी आंदोलन को वैचारिक तथा नैतिक आधार प्रदान किया। गांधीजी राष्ट्रीय एकता के प्रबल समर्थक थे और प्रेमचन्द ने अपने साहित्य के द्वारा उसी एकता को सुदृढ़ करने का निरंतर प्रयास किया। प्रेमचन्द का साहित्य यह सिद्ध करता है कि साहित्य समाज को जोड़ने, दिशा देने तथा परिवर्तन की चेतना जगाने की अद्वितीय क्षमता रखता है। अतः प्रस्तुत शोधपत्र इस निष्कर्ष पर पहुँचता है कि प्रेमचन्द का साहित्य गांधीवादी विचारधारा से प्रेरित होकर भारतीय समाज को नैतिक, सामाजिक एवं राष्ट्रीय स्तर पर एक सूत्र में बाँधने का एक सफल और सार्थक प्रयास है, जिसकी प्रासंगिकता आज भी उतनी ही महत्वपूर्ण है।

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8 CHAPTER

A Reformative Vision of George Eliot towards Christianity

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Abstract

Christian belief was the defining belief of the Victorian age. The term "Victorian" has come to denote a specific set of beliefs, attitudes, and experiences, many of which were shared by citizens of a number of nations, including Russia, America, Spain, and Scandinavia, and which were represented in nineteenth-century literature and civilization. Religion had an impact on political and social life. During this period, significant scientific breakthroughs and advancements were also made. From Darwin's *Origin of Species* to Strauss's *Life of Jesus*, new approaches and viewpoints undermine faith in the Bible's literal authenticity. During the Victorian era, developments in various fields led to the questioning of old religious beliefs. Various facets of the belief system were contested and viewed with scepticism. The Victorian era witnessed significant political and social transformation, the quick development of industries, the writings of Charles Darwin and Charles Dickens, the growth of the railway and shipping industries, amazing scientific breakthroughs, and the revolution brought about by the development of the telephone and telegraph.

Keywords: Christian, Belief, Victorian, Faith etc.

Despite the decline of religion throughout the Victorian era, there were still many devout priests, missionaries, theologians, and authors who sought to uphold Christian doctrine. Some religious followers dedicated their life to spreading their faith by relocating to different countries. Some authors used their writing as a tool to keep the religion alive. Most of the well-known female writers of this time were devoted Christians. Emily Dickinson, a unique writer, Mrs. Gaskell, a Unitarian, and the Broad Church Bronte sisters all wrote extensively about their beliefs. Theologian George Eliot

concentrated on reinterpreting Christianity after being profoundly impacted by a religion in which she eventually lost some degree of faith. Nevertheless, a number of male authors, such as Thackeray and Anthony Trollope, were devoted Christians.

Mary Ann Evans, well known by her pen name George Eliot. In 1819, she was born in Nuneaton. She attended a nearby Dame's school before attending a residential school in the Nuneaton suburbs. She was Robert Evans' third daughter from his second wife. At school, her consequential character was seen. She frequently spied on her teachers and older kids from the corner. As a result, she was perceived as a clumsy girl. "Miss Lewis, the principal of the school triggered her intellectual curiosity and an ever increasing flame to learn".

Early on, Evans shown a peculiar interest in religious topics. Some family members were ardent Methodists, although her parents were members of the Established Church. They spent a lot of time discussing religion, and many of them were involved in its instillation in one way or another. Marian paid close attention to the sermons that were delivered at the local church. She acknowledges in one of her letters that she is unable to give a clear explanation of her spiritual state, that she has been overtaken by worldly people, and that one of her biggest obstacles is her need for human recognition.

Marian Evans gained a fresh perspective on many aspects of life and Christianity as a result of the intellectual climate of this era. Her philosophical beliefs and the fundamentals of reflective thinking were gradually developed. She developed the ability to think independently in the home of one of her close friends, which is where her positivist beliefs were initially evident.

Marian Evans spent a lot of time with a group of free-thinking, intelligent people who appear to have completely brainwashed her with their viewpoints. Though they were ardent students of philosophy and science, none of them had completely adopted or rejected Christianity or theism. The tenets she later held so firmly were established here, and many of the beliefs she discussed in her books were fully developed even at this time. Here, Comte, Spencer, and Lewes' teachings took up all of her thoughts.

She raced through mountains of Christian literature, both radical and mainstream, in her quest for authentic truth. George Eliot wrote a lot of letters, and her correspondence reveals the depth of her religious convictions. A few passages are provided as unquestionable proof of her personal beliefs. She writes to her friend Mrs Pears in March 1942 despite having split from her father over the debate surrounding church attendance, which she understands

is an unnecessary social practice:

“I fully participate in the belief that the only heaven here or hereafter is to be found in conformity with the will of the supreme, a continued aiming at the attainment of the perfect ideal, the true Logos that dwells in the bosom of the one father” (Haight).

Her works demonstrate that she is a writer with the intelligence to follow through on her beliefs. Her novels' strong moral message, which has been discussed by a number of academics. "Her childhood convictions remained as strong as ever, and she never wrote a word in her novels of which her father could have complained that it violated scriptural teachings," notes Grant C. Knight.

In George Eliot's novel "Adam Bede," religion plays a significant role in shaping the characters' lives and the moral fabric of the community. Religion, especially the Methodist faith, has a significant impact on the people and their relationships in the story's rural setting in England. Eliot is a supporter of Methodism. She examines religious conditions using Seth's and Dinah's Methodism. Eliot placed a great deal of emphasis on religion. When Eliot wrote this book, Methodism and other forms of nonconformism to the Church of England (the Anglican Church) were quite unpopular. However, her writing was founded on some personal experiences with Methodism and was very extensively researched.

Another significant aspect of Adam Bede is methodism. The preacher John Wesley and his brother Charles started this Protestant movement in England in 1729. The belief that only God's chosen people can be saved is known as predestination, and it is rejected by the faith.

Henry VIII of England founded the Anglican Church after he formally broke away from Catholicism in 1534 after the Pope forbade him from divorcing Catherine of Aragon so he might marry someone else. Bede, Adam. Methodism's theological focus on the premise that everyone can be saved, which is shared by other churches, appealed to England's new industrial workers.

John Wesley and his younger brother Charles founded Methodism in England. The two concentrated on studying the Bible and their own interpretations of Jesus' teachings. They also placed a strong emphasis on doing good actions, including visiting the sick in hospitals and the guilty in jails in an effort to preserve the souls of those who were about to pass away. In accordance with her tradition, Dinah visits Hetty in prison as a Methodist attempting to rescue her soul in addition to being her friend and cousin.

Eliot put a lot of effort into identifying the precise discourse style that Methodists typically used. She read Southey's *Life of Wesley* and used details about open-air revivals, evangelism, and bibliomancy for her novel.

Eliot's personal encounter with Methodism was connected to her aunt, Elizabeth Evans, who wed Samuel Evans. She was one of the few female preachers who contributed to the early spread of Methodism in Britain. This aunt serves as a major model for Eliot's character Dinah. Eliot attributes the "germ" of her inspiration to start working on *Adam Bede* to an emotional story her aunt told her when she was younger.

Her aunt described traveling to a Nottingham jail to minister to a young woman who was sentenced to death for murdering her own baby. To see her execution, Elizabeth Evans rode in the death-cart with her. This journey was the focal point of Eliot's initial conception of *Adam Bede*.

Characters like Dinah Morris and *Adam Bede* receive moral instruction from religion. Both characters have strong religious beliefs and make an effort to live by Christian values. Their faith guides them to live moral lives by influencing their choices and actions. A major component of the protagonists' social lives is the religious community. They get together for prayer sessions, worship, and other religious events, deepening their relationships and reaffirming their common ideals. The work highlights instances of moral faults and hypocrisy within the religious community, despite the emphasis on devotion and virtue.

For instance, despite his seeming dedication to Christian standards, Arthur Donnithorne, a well-known member of the group, acts immorally. This emphasises the conflict between declared faith and behaviour. Characters who have done wrong can find forgiveness and atonement through religion. Dinah Morris, in particular, exemplifies this notion by offering forgiveness and spiritual rejuvenation to individuals who have deviated from the path of virtue. The protagonists struggle with existential issues pertaining to morality, faith, and life's purpose. In uncertain or difficult times, religion offers a framework for answering these issues and finding comfort.

Eliot criticises the institutional features of organised religion even as she presents religion as a source of moral instruction and social assistance. The limitations and flaws of religious organisations, like the Church of England, which is shown to be disconnected from the demands of the general public, are depicted in the book. Eliot criticises the institutional features of organised religion while also illustrating the positive impact of religion on personal morals.

Eliot highlights the narrow-mindedness and hypocrisy of some religious leaders and organisations, especially in the way they treat people who don't fit in with society's norms. A number of the novel's protagonists experience personal challenges pertaining to their beliefs. For instance, Methodist preacher Dinah Morris struggles with her calling and the difficulties of serving others. After a personal catastrophe, Adam Bede himself has a crisis of faith, questioning his views and turning to religion for comfort. Within the Hayslope community, religion acts as a unifying factor. The characters take part in religious rites like church services, which provide chances for communal cohesion and social engagement. Their sense of identity and belonging is frequently shaped by their religious membership.

Adam's final speech and song returning to the beginning of the novel, I'd like to underline the structural relevance of Adam's song. In the workshop, this is the first thing we hear. Adam is singing Thomas Ken's famous hymn, which begins, "Awake, my soul, and with the sun/Thy daily stage of duty run." The final voice we hear at the close of the chapter is Adam's, who resumes singing the fourth line, "Let all thy converse be sincere, Thy conscience as the noonday clear..." It should be noted that the final stanza contains the well-known Doxology about God.

"Praise God, from whom all blessings flow;

Praise Him, all creatures here below;

Praise Him above, ye heavenly host;

Praise Father, Son, and Holy Ghost."(Adam Bede)

Humanitarianism and social justice are key elements in Eliot's reworking of Christianity. She criticises the hypocrisy of people and organisations that claim to be religiously devout yet fall short of Christian morality. Personas such as Dorothea Brooke in "Middlemarch" and Dinah Morris in "Adam Bede" exemplify these ideals and strive to build a society that is more compassionate and just. Eliot challenges narrow sectarianism and religious exclusivism in his works, which frequently exhibit a spirit of tolerance and universalism. She examines the notion that religious variety should be welcomed rather than feared and that moral virtue may be found in people from all walks of life. Eliot prioritises inner redemption and individual spirituality over formal religion in several of her books. Instead of following religious rites or ideologies, characters experience spiritual transformations by self-reflection, moral development, and deeds of kindness.

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9 CHAPTER

Haplotype-Based Breeding: A New Paradigm for Precision Crop Improvement

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Abstract

The growing complexity of breeding objectives, driven by climate change, resource limitations and the need for sustainable agricultural productivity, necessitates breeding strategies that can more effectively harness the genetic variation underlying complex traits. Haplotype-based breeding has emerged as a powerful advancement in crop improvement, redefining the unit of selection from individual molecular markers to a combination of linked alleles that better represents the functional genetic architecture of plant genomes. By capturing multi-allelic variation within genes and genomic regions, haplotypes provide a biologically meaningful framework for

understanding and selecting favorable genetic combinations governing quantitative traits. Recombination patterns in plant genomes result in haplotype blocks whose structure and diversity vary across species and breeding systems, influencing trait inheritance and selection efficiency. Unlike single-marker approaches, haplotype-based strategies can account for local epistatic interactions and allele series, thereby improving the resolution of genetic mapping and enhancing the accuracy of genomic prediction. Evidence from major crops such as rice, wheat and maize demonstrates that haplotype-driven selection enables the identification of superior allele combinations associated with yield, stress tolerance and environmental adaptation that often remain undetected using conventional SNP-based analysis. The integration of haplotype-based breeding with modern technologies, including double haploids, speed breeding, genomic selection and efficient haplotype imputation frameworks, further accelerates genetic gain by enabling rapid fixation and deployment of elite haplotypes. Advances in pangenomics, high-throughput phenotyping and data-driven prediction models are expected to expand the scope and impact of haplotype-based approaches. Haplotype-based breeding provides a robust and scalable pathway for precision crop improvement, offering significant potential to enhance productivity, resilience and sustainability in contemporary plant breeding programs.

Keywords: Haplotype-based breeding, crop improvement, quantitative traits, genomic selection, genetic mapping, precision breeding.

1. Introduction to Haplotype-Based Breeding

Plant breeding has undergone a major transformation from phenotypic selection to molecular and genomic approaches that enable breeders to track genetic variation underlying agronomically important traits. Marker-assisted selection (MAS), based largely on individual DNA markers, has been particularly effective for traits governed by major genes^[1]. However, most economically important traits in crops, such as yield, drought tolerance, heat tolerance and nutrient use efficiency, are quantitative in nature and controlled by many loci with small effects that are often physically linked to chromosomes^[2]. In such cases, selection based on single markers frequently fails to capture the full spectrum of genetic variation influencing the phenotype, leading to slower genetic gains, particularly across diverse environments and genetic backgrounds^[3].

Haplotype-based breeding has emerged as a powerful genomics-assisted

strategy to overcome these limitations by shifting the unit of selection from individual markers to haplotypes, which are combinations of linked alleles inherited together due to limited recombination ^[4]. Because haplotypes integrate information from multiple variants within a genomic region, they more accurately reflect the functional genetic architecture underlying complex traits, especially in regions exhibiting strong linkage disequilibrium ^[5]. This is particularly important for genes that harbor multiple functional polymorphisms in encoding or regulatory regions, where the combined effect of these variants determines trait expression rather than any single polymorphism acting alone ^[6]. As a result, haplotypes often show stronger, more stable and more biologically meaningful associations with phenotypes than single-nucleotide polymorphisms ^[7].

Recent advances in next-generation sequencing, high-density genotyping platforms and computational methods have made haplotype discovery, phasing and analysis feasible at the whole-genome scale ^[8]. These technological developments, coupled with improved statistical models and imputation frameworks, have enabled breeders to routinely identify superior haplotypes and deploy them effectively in breeding populations ^[6]. Consequently, haplotype-based breeding is increasingly viewed not as a replacement for existing genomic approaches, but as a complementary strategy that enhances marker-assisted selection and genomic selection by providing a more realistic representation of genetic variation and improving selection accuracy for complex traits ^[7]. This paradigm shift towards haplotype- driven selection marks an important step towards precision crop improvement and accelerated genetic gain in modern plant breeding programs ^[8, 5].

2. Haplotypes and Their Role in Plant Genomes

The organization of genetic variation in plant genomes is shaped by recombination, mutation and selection. Recombination does not occur uniformly along chromosomes, instead certain regions experience low recombination rates, causing alleles at neighboring loci to remain associated across generations ^[9]. These regions form haplotype blocks, whose size and structure vary among crop species and populations depending on the mating system and evolutionary history. Self-pollinated crops such as rice and wheat generally possess longer haplotype blocks due to reduced effective recombination, whereas cross-pollinated crops like maize exhibit shorter haplotype blocks and greater haplotype diversity ^[10, 7].

Haplotypes are biologically meaningful units because many genes harbor multiple functional variants in coding and regulatory regions that jointly influence gene expression and phenotype^[11]. Selection based on a single SNP captures only a fraction of this variation, whereas haplotypes represent the complete allelic configuration of a genomic region and can accommodate multiple-allelic variation and local epistatic interactions that are common in complex traits^[5]. The conceptual advantage of haplotype-based selection over single-marker selection is illustrated in Figure 1^[12].

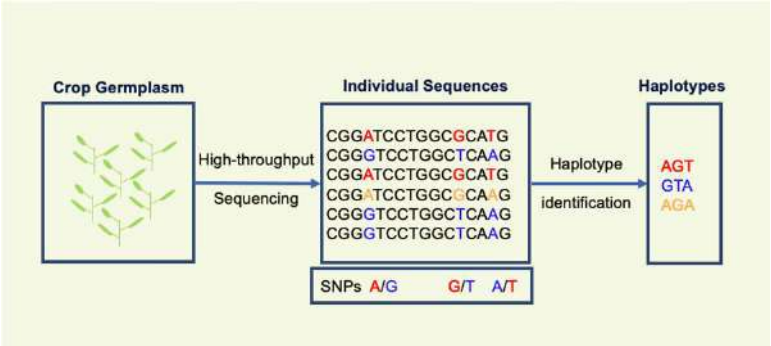


Fig. 1: Conceptual overview of haplotype-based breeding

3. Identification and Analysis of Haplotypes

Haplotype-based breeding begins with the generation of dense genotypic data through whole-genome resequencing or high-density SNP genotyping platforms. Following variant discovery, haplotypes are defined by grouping neighboring polymorphisms that tend to be inherited together. This grouping can be achieved using several approaches, including linkage disequilibrium-based block definition, fixed physical windows and gene-based haplotypes that encompass polymorphisms within annotated gene boundaries^[13, 14]. Among these approaches, gene-based haplotypes are particularly attractive for plant breeders because they align directly with functional genomic regions and allow straightforward biological interpretation of haplotype-trait relationships, especially when genes harbor multiple functional variants affecting phenotype^[15].

Accurate haplotype identification often requires phasing, which determines the arrangement of alleles on homologous chromosomes. Phasing can be performed using population-based statistical algorithms, pedigree information, or sequencing technologies that provide long-range haplotype information^[16, 17]. Recent advances, such as the Practical Haplotype Graph

(PHG), have greatly enhanced the practical utility of haplotype-based breeding by enabling efficient storage of known haplotypes and accurate imputation of haplotype states from low-density genotyping data. This approach substantially reduces genotyping costs while preserving genome-wide haplotype resolution, making haplotype analysis feasible for large breeding populations^[18, 19].

4. Use of Haplotypes in Genetic Mapping and Selection

Haplotype-based association mapping extends conventional genome-wide association studies by testing groups of linked variants (haplotype classes) rather than individual SNPs. Because many genes and quantitative trait loci contain multiple functional polymorphisms, haplotype-based tests can capture the combined effects of these variants more effectively than single-marker analysis, particularly in regions of strong linkage disequilibrium^[20, 21]. By increasing the correlation between genetic predictors and underlying causal variation, haplotype-based association mapping improves statistical power and reduces false negatives that arise from weak marker-trait linkage. As a result, haplotype-based analysis has identified superior allele combinations controlling agronomic traits in several crops that were not detected using single-marker GWAS approaches^[22, 15].

Beyond trait mapping, haplotypes have been increasingly incorporated into genomic selection frameworks to improve prediction accuracy for complex traits. Unlike by allelic SNPs, multiple-allelic haplotype predictors can represent allelic series and capture short-range epistatic interactions within genomic regions, which are important components of the genetic architecture of quantitative traits⁵. Empirical studies in wheat have demonstrated that haplotype-based genomic prediction improves accuracy for yield, grain quality and stress-related traits when haplotype block size and training population composition are carefully optimized^[23, 24]. These results indicate that haplotypes can enhance selection efficiency when applied judiciously and in combination with conventional genomic prediction strategies.

5. Applications of Haplotype-Based Breeding in Crop Plants

5.1. Rice

Rice has emerged as a model system for haplotype-based breeding owing to its well-annotated reference genome, extensive resequencing resources and high genetic diversity. Gene-based haplotype analysis has been widely used to dissect complex traits such as root architecture, shoot growth, yield

components and nutrient-use efficiency. For instance, superior haplotypes associated with early root vigor under low-nitrogen and dry direct-seeded conditions, providing breeders with well-defined donor haplotypes for stress-resilient rice improvement have been identified²². Similarly, genome-wide association mapping with gene-based haplotype analysis enables the identification of functionally distinct haplotypes controlling shoot length, highlighting the increased resolution of haplotype-level analysis^[15].

Further studies have shown that haplotype variation within key rice genes influences grain filling, yield stability and environmental adaptation, reinforcing the practical value of haplotype-based selection for complex traits^[25-27]. Importantly, many superior haplotypes identified in these studies have been converted into breeder-friendly diagnostic markers, facilitating their direct deployment in marker-assisted selection and pre-breeding programs.

5.2. Wheat

In wheat, the large polyploid genome and the quantitative nature of most agronomic traits limit the effectiveness of single-marker-based selection. Haplotype-based approaches have therefore gained attention for improving both trait dissection and genomic prediction. Multi-allelic haplotype models have been shown to capture genetic variation across homoeologous chromosomes and linked genomic regions more effectively than individual SNPs^[28].

Subsequent studies confirmed that haplotype-based predictors can outperform SNP-based models for several agronomic traits, provided that haplotype block size and structure are carefully defined and validated within the target population^[23, 24]. These findings support the use of haplotype-based breeding as a complementary strategy to conventional genomic selection in wheat improvement programs.

5.3. Maize

Maize is characterized by rapid linkage disequilibrium decay and high genetic diversity, which initially suggested limited applicability of haplotype-based approaches. Nevertheless, haplotype-based breeding has proven effective at loci with strong functional relevance. Distinct haplotypes at the *ZmCCT* locus demonstrated that a superior haplotype (H5) significantly improved yield, drought tolerance and stalk-rot resistance across environments. The agronomic advantages of the *ZmCCT* H5 haplotype, including improved yield and resilience, are depicted in Figure 2^[29].

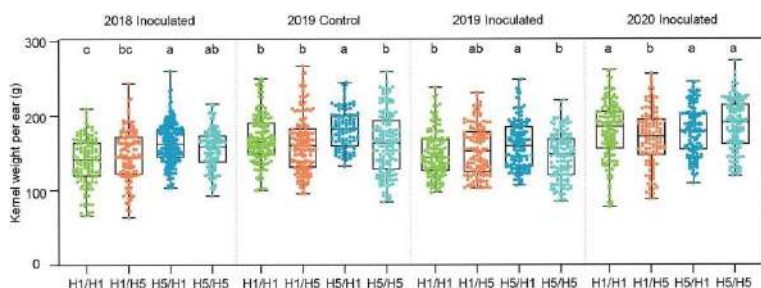


Fig. 2: Performance comparison of maize plants with different ZmCCT haplotypes showing yield, stalk-rot resistance and drought tolerance effects

These results demonstrate that even in highly recombining species such as maize, haplotype-based selection can successfully exploit functionally important genomic regions when haplotypes are carefully defined and validated. Additional examples from maize further highlight the potential of haplotype-based breeding to identify elite allele combinations contributing to yield stability and stress resilience under diverse production environments^[30, 31].

6. Integration of Haplotype-Based Breeding with Modern Breeding Technologies

Haplotype-based breeding achieves its greatest impact when integrated with modern breeding technologies that accelerate genetic gain. Once superior haplotypes are identified, doubled haploid technology provides an efficient means to rapidly fix these haplotypes into completely homozygous lines, thereby reducing breeding cycle time and enabling early and accurate phenotypic evaluation^[32-34]. This integration is particularly valuable for complex traits, where rapid fixation of favorable haplotypes allows breeders to assess their true genetic effects without confounding segregation

Speed breeding further complements haplotype-based selection by accelerating generation turnover and increasing opportunities for recombination and selection within a short time frame^[35, 36]. In parallel, genomic selection frameworks can be strengthened by incorporating haplotype predictors alongside genome-wide SNP effects, combining biological interpretability with predicting accuracy for complex traits^[37].

7. Visualization and Interpretation of Haplotypes in Breeding Programs

Effective visualization is essential for translating haplotype information

into practical breeding decisions. Haplotype blocks are commonly represented as colored segments along chromosomes, allowing breeders to track favorable haplotypes across individuals, families and breeding cycles. Such visual tools simplify the identification of donor haplotypes, facilitate the design of strategic crosses and aid in monitoring haplotype introgression during selection. Graph-based representations, particularly those used in PHG and pangenome frameworks, provide a more comprehensive view of haplotype diversity by depicting alternative haplotype paths within a genomic region^[38, 19]. These representations enable efficient comparison among genotypes and improve understanding of structural and allelic variation at the population level, thereby enhancing decision-making in genomics-assisted breeding programs.

8. Challenges and Limitations

Despite its advantages, haplotype-based breeding faces several practical and methodological challenges. Accurate haplotype inference relies on high-quality genotypic data, reliable phasing and representative reference panels. Deficiencies in any of these components can reduce selection accuracy. Rare haplotypes with potentially large effects are particularly difficult to detect and validate, especially in small or narrowly sampled breeding populations. Population structure and relatedness can also confound haplotype-trait associations if not properly accounted for, leading to spurious inferences. Moreover, not all traits benefit equally from haplotype-based approaches and the effectiveness of haplotype selection depends on the genetic architecture of the trait and the haplotype block definition used. Consequently, empirical validation within target breeding populations remains essential before large-scale^[8, 39, 24].

9. Future Prospects

The future of haplotype-based breeding lies in its integration with emerging genomic and phenotyping technologies. Pangenome resources are expected to play a central role by enabling haplotypes to incorporate structural variants and presence-absence variation, thereby providing a more complete representation of functional genome diversity^[40]. Advances in high-throughput phenotyping will further improve the accuracy of haplotype-trait associations under diverse environmental conditions. In addition, machine learning and artificial intelligence approaches that explicitly model haplotype structure and non-linear interactions hold promise for improving prediction accuracy for complex traits^[41]. As sequencing costs continue to decline and

analytical pipelines become more standardized, haplotype-based breeding is expected to transition from a specialized strategy to a routine component of precision crop improvement programs^[7].

10. Conclusion

Haplotype-based breeding represents a significant advancement in plant breeding by providing a biologically meaningful unit of selection that captures complex genetic variation more effectively than single markers. Evidence from major crops such as rice, wheat and maize demonstrates that haplotypes enhance trait mapping, improve genomic prediction and facilitate the identification of agronomically valuable allele combinations. When integrated with modern breeding technologies, including doubled haploids, speed breeding, genome selection and cost-effective haplotype imputation platforms, haplotype-based breeding offers a powerful and flexible framework for accelerating genetic gain and achieving sustainable crop improvement.

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10 CHAPTER

Intelligent Automation and Smart Computing: Emerging Computer Technologies and Real-World Applications

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Abstract

Intelligent automation and smart computing represent a transformative shift in modern computer technology, enabling systems to operate with enhanced autonomy, adaptability and decision-making capabilities ^[1]. Traditional computing infrastructures, which primarily relied on predefined logic and manual intervention, are increasingly being replaced by intelligent frameworks that integrate artificial intelligence, distributed computing and adaptive automation mechanisms ^[2]. This chapter presents a comprehensive exploration of intelligent automation and smart computing as emerging paradigms shaping contemporary computer technologies and real-world applications.

The chapter begins by examining the foundational concepts of intelligent

automation and the technological drivers that support its evolution, including machine learning, robotic process automation, cloud computing and Internet of Things integration ^[3-5]. It further investigates the smart computing paradigm, emphasizing architecture, system components and workflow models that enable dynamic and context-aware operations. Emerging technologies such as edge computing, autonomous AI systems and distributed infrastructures are discussed as critical enablers of scalable automation ^[6-8].

In addition, the chapter analyzes practical applications across healthcare, smart cities, enterprise environments, education and cybersecurity, demonstrating how intelligent automation enhances efficiency, resilience and decision support ^[9-11]. The discussion also addresses technical challenges and ethical considerations, including system reliability, data privacy, transparency and workforce implications ^[12]. Finally, future trends such as self-optimizing infrastructure, agentic computing and multimodal intelligent environments are explored to highlight the long-term impact of smart computing on digital ecosystems ^[13].

This chapter aims to provide researchers, academicians and practitioners with a structured understanding of intelligent automation and smart computing as core pillars of next-generation computer technologies.

Keywords: Intelligent Automation, Smart Computing, Adaptive Systems, Autonomous Computing, Edge Computing, Digital Transformation, Emerging Computer Technologies, Real-World Applications.

1. Introduction

The rapid evolution of computer technology has fundamentally transformed how digital systems remembering, processing and acting upon information operate across modern environments. Early computing systems were primarily designed for deterministic tasks, relying on predefined instructions and static workflows that required continuous human oversight. While these systems enabled large-scale data processing and automation of repetitive operations, they lacked adaptability and contextual awareness. With the emergence of intelligent computing paradigms, computer systems have gradually transitioned from passive tools to active decision-support entities capable of learning, reasoning and autonomous execution ^[14].

This transformation has been driven by the growing complexity of digital ecosystems, where organizations must process massive data streams, respond to dynamic conditions and deliver real-time services. Traditional automation approaches, which depend heavily on rule-based logic, struggle to cope with

unpredictable environments and evolving user requirements. Consequently, intelligent automation has emerged as a critical paradigm that integrates artificial intelligence, machine learning and robotic process automation to enable systems that can analyze context, optimize workflows and continuously improve performance ^[15]. Rather than merely executing predefined instructions, intelligent automation systems support adaptive decision-making and proactive problem resolution.

Parallel to the rise of intelligent automation, the concept of smart computing has gained prominence as a holistic framework for designing computing environments that are context-aware, interconnected and self-optimizing. Smart computing extends beyond individual algorithms to encompass infrastructure, data management and interaction models that enable systems to respond intelligently to environmental changes. The integration of cloud computing, edge computing and Internet of Things technologies has accelerated this shift, allowing distributed systems to collaborate and deliver scalable intelligence across domains ^[16].

The convergence of intelligent automation and smart computing is reshaping modern computer technologies by enabling autonomous workflows, predictive analytics and intelligent service delivery. In healthcare, smart computing systems assist clinical decision-making and operational efficiency; in smart cities, they optimize transportation and resource allocation; and in enterprise environments, they enhance process management and cybersecurity resilience ^[17]. These applications illustrate how intelligent computing is no longer limited to specialized research environments but has become central to everyday digital operations.

Despite these advancements, the widespread adoption of intelligent automation introduces new challenges related to system reliability, interoperability, ethical governance and workforce transformation. As computing systems assume greater decision authority, ensuring transparency, accountability and trust becomes essential. Addressing these concerns requires interdisciplinary approaches that combine technological innovation with regulatory and ethical frameworks ^[18].

This chapter aims to provide a comprehensive examination of intelligent automation and smart computing within the broader context of emerging computer technologies. It explores foundational concepts, architectural models, enabling technologies and real-world applications, while also addressing challenges and future research directions. By presenting both theoretical insights and practical perspectives, the chapter highlights how

intelligent automation and smart computing are redefining the capabilities and impact of contemporary computer systems.

2. Foundations of Machine Learning and Deep Learning

2.1. Concept of Intelligent Automation

Intelligent automation represents the convergence of traditional automation practices with advanced computational intelligence, enabling systems to perform tasks that previously required human reasoning, judgment and adaptability^[19]. Unlike conventional automation, which focuses primarily on executing repetitive operations based on fixed rules, intelligent automation incorporates learning mechanisms that allow systems to interpret data, identify patterns and adjust behavior dynamically. This shift marks a fundamental transition from procedural computing to cognitive computing environments.

The concept of intelligent automation is closely associated with the development of intelligent agents capable of perceiving their environment, making decisions and executing actions with minimal supervision. These systems operate within feedback-driven loops, where outcomes inform future decisions, enabling continuous improvement. Such capabilities are particularly valuable in complex environments where predefined workflows are insufficient to handle variability and uncertainty^[20].

A defining characteristic of intelligent automation is its ability to integrate multiple technological layers. Machine learning models provide predictive insights, robotic process automation handles operational execution and analytics platforms facilitate monitoring and optimization. Together, these components create automation ecosystems that are adaptive rather than static. As a result, intelligent automation is increasingly viewed as a strategic enabler of digital transformation rather than merely a productivity tool^[21].

2.2. Core Technologies behind Intelligent Automation

The effectiveness of intelligent automation depends on a combination of enabling technologies that collectively support perception, reasoning, execution and learning. Artificial intelligence serves as the central intelligence layer, allowing systems to interpret unstructured data, generate predictions and support decision-making processes. Machine learning techniques enable these systems to improve performance over time by learning from historical and real-time data, thereby reducing dependence on manual intervention^[22].

Robotic process automation plays a complementary role by automating structured digital tasks such as data entry, workflow coordination and system

integration. When combined with artificial intelligence, RPA evolves into cognitive automation capable of handling semi-structured and unstructured processes. This integration significantly expands the scope of automation across enterprise and service environments ^[23].

Cloud computing and distributed infrastructures provide the scalability required for intelligent automation systems to operate across large datasets and geographically dispersed environments. Edge computing further enhances this capability by enabling localized processing, reducing latency and supporting real-time decision-making in IoT-driven scenarios. These technological layers collectively form the backbone of modern intelligent automation architectures ^[24].

2.3. Benefits and Limitations of Intelligent Automation

The adoption of intelligent automation offers several advantages, including improved operational efficiency, reduced human error and enhanced decision support. By automating routine processes, organizations can allocate human resources to strategic and creative tasks, thereby increasing overall productivity. Intelligent automation also enables predictive maintenance, proactive service delivery and personalized user experiences, which contribute to improved organizational performance ^[25].

Another significant benefit is scalability. Intelligent automation systems can process large volumes of data and execute tasks across multiple platforms simultaneously, making them suitable for complex digital ecosystems. Additionally, continuous learning capabilities allow these systems to adapt to evolving conditions without extensive reconfiguration, supporting long-term sustainability of digital operations ^[26].

However, intelligent automation is not without limitations. Implementation complexity, integration challenges with legacy systems and the need for high-quality data can hinder adoption. Furthermore, increased reliance on automated decision-making raises concerns related to transparency, bias and accountability. Addressing these limitations requires careful system design, governance frameworks and human oversight to ensure responsible deployment ^[27].

3. Smart Computing Paradigm

3.1. Concept of Smart Computing

Smart computing represents a paradigm shift in the design and operation

of computer systems, emphasizing adaptability, context awareness and continuous optimization rather than static processing workflows [28]. Traditional computing environments were primarily focused on executing predefined algorithms on centralized infrastructures. In contrast, smart computing systems integrate sensing, analytics and intelligent decision-making to create environments that respond dynamically to changing conditions.

The defining feature of smart computing is its ability to operate across heterogeneous environments where data originates from multiple sources, including sensors, user interactions, enterprise platforms and distributed networks. By leveraging real-time analytics and automation mechanisms, smart computing systems can identify patterns, predict outcomes and initiate actions without extensive manual intervention. This capability enables computing infrastructures to transition from reactive operation to proactive service delivery [29].

Smart computing also reflects the increasing convergence of physical and digital systems. In cyber-physical environments such as smart cities and intelligent healthcare platforms, computing systems must process continuous data streams while maintaining reliability and scalability. As a result, smart computing is often characterized by distributed intelligence, collaborative processing and adaptive resource management [30].

3.2. Components of Smart Computing Systems

Smart computing systems are typically structured around interconnected layers that collectively support intelligent operation. The first layer is the data layer, which captures information from diverse sources such as IoT devices, enterprise databases and user-generated content. Effective data management is critical, as the quality, availability and timeliness of data directly influence system intelligence [31].

Above the data layer lies the intelligence layer, which includes machine learning models, decision engines and analytics frameworks. This layer transforms raw data into actionable insights, enabling systems to identify anomalies, optimize workflows and support autonomous decision-making. The intelligence layer often incorporates both predictive and prescriptive analytics, allowing systems not only to forecast outcomes but also to recommend appropriate actions [32].

The infrastructure layer provides the computational resources necessary

to support smart computing operations. Cloud platforms enable scalable processing, while edge computing supports low-latency decision-making close to data sources. Network connectivity ensures seamless communication among distributed components, allowing smart computing environments to function as integrated ecosystems rather than isolated systems^[33].

Together, these layers create a cohesive framework that supports continuous perception, reasoning and action—core characteristics of intelligent computing environments.

3.3. Smart Computing vs Conventional Computing

Smart computing systems, by contrast, incorporate feedback mechanisms that allow them to adjust behavior based on environmental changes. For example, resource allocation can be optimized automatically in response to demand fluctuations and predictive analytics can identify potential failures before they occur. These capabilities enable organizations to move from reactive management to proactive optimization^[35].

The distinction between smart computing and conventional computing lies primarily in adaptability and autonomy. Conventional computing systems operate within predefined boundaries, executing tasks based on static logic and requiring manual updates to accommodate changes. While effective for structured environments, this approach becomes inefficient in dynamic contexts where conditions evolve rapidly^[34].

Another key difference is the role of human interaction. Conventional systems rely heavily on human supervision for monitoring and decision-making, whereas smart computing environments support collaborative human-machine workflows. Humans provide strategic oversight while automated systems handle operational complexity. This collaborative model enhances efficiency while maintaining accountability and control^[36].

The shift toward smart computing therefore represents not only a technological evolution but also a transformation in how computing systems contribute to organizational intelligence and digital service delivery.

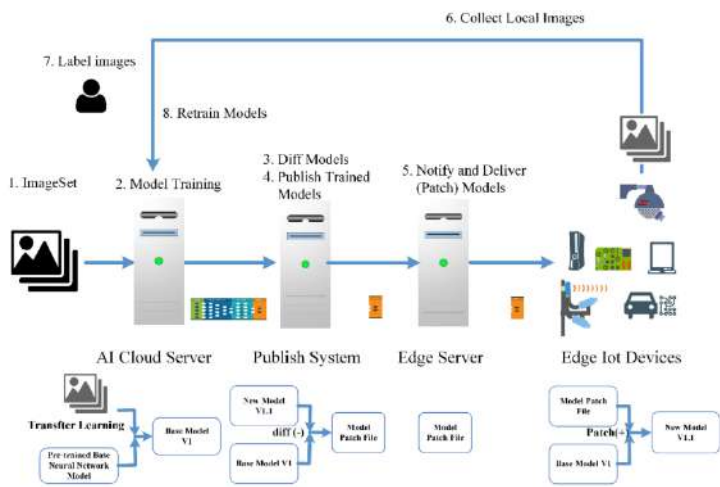


Fig. 1: Smart Computing Architecture

4. Emerging Computer Technologies Enabling Automation

The rapid advancement of intelligent automation has been made possible by a set of emerging computer technologies that extend the capabilities of traditional computing environments. These technologies provide the scalability, connectivity and computational intelligence required to support adaptive automation across distributed systems. Rather than operating independently, they function as interconnected enablers that collectively support smart computing ecosystems^[37].

4.1. Cloud Computing and Distributed Systems

Cloud computing has become a foundational technology for intelligent automation by providing scalable infrastructure, on-demand resources and flexible deployment models. Automation systems rely on cloud platforms to process large datasets, train machine learning models and orchestrate workflows across geographically distributed environments. The elasticity of cloud computing allows organizations to scale automation initiatives without significant upfront infrastructure investment^[38].

Distributed computing architectures further enhance automation by enabling parallel processing and resource sharing across multiple nodes. This approach improves system reliability and performance, particularly for data-intensive applications such as predictive analytics and large-scale monitoring systems. Cloud-native automation frameworks leverage microservices and

containerization to support modular and resilient automation pipelines ^[39].

4.2. Edge and Fog Computing

While cloud computing provides centralized processing capabilities, edge and fog computing address the need for low-latency decision-making in real-time environments. Edge computing enables data processing near the source of data generation, reducing network congestion and improving responsiveness. This capability is essential in applications such as autonomous vehicles, industrial automation and healthcare monitoring systems ^[40].

Fog computing extends this concept by introducing intermediate processing layers between edge devices and cloud infrastructure. By distributing computational tasks across multiple layers, fog computing enhances scalability and reliability while maintaining near real-time performance. The integration of edge and fog computing with intelligent automation enables context-aware decision-making in environments where immediate response is critical ^[41].

4.3. Internet of Things Integration

The Internet of Things (IoT) plays a crucial role in enabling intelligent automation by providing continuous streams of real-world data. Sensors, wearable devices and connected infrastructure generate information that automation systems use to monitor conditions, detect anomalies and trigger automated responses. IoT-driven automation is particularly impactful in smart cities, industrial environments and healthcare systems where physical processes must be managed dynamically ^[42].

The combination of IoT and intelligent automation creates cyber-physical systems capable of real-time coordination between digital intelligence and physical operations. However, this integration also introduces challenges related to interoperability, data security and device management, highlighting the importance of standardized communication protocols and robust system design ^[43].

4.4. Generative and Autonomous AI Systems

Recent developments in generative and autonomous artificial intelligence have significantly expanded the scope of intelligent automation. Generative models can produce content, simulate scenarios and assist in decision-making processes, enabling automation systems to handle complex cognitive tasks. Autonomous AI systems extend these capabilities by

operating as goal-driven entities that plan, execute and adapt actions over time [44].

These technologies enable automation frameworks to move beyond rule execution toward reasoning-driven workflows. For example, autonomous systems can optimize resource allocation, manage workflows dynamically and support personalized service delivery. The integration of generative and autonomous AI with distributed computing infrastructures represents a major step toward fully intelligent computing environments [45].

Table 1: Comparison of Emerging Computer Technologies Supporting Intelligent Automation

Technology	Core Function	Role in Intelligent Automation	Key Advantages	Example Applications
Artificial Intelligence (AI)	Enables machines to simulate human intelligence	Provides decision-making capability	Adaptive learning, predictive analysis	Virtual assistants, decision systems
Machine Learning (ML)	Learns patterns from data	Improves automation accuracy over time	Data-driven optimization	Fraud detection, recommendation systems
Deep Learning (DL)	Uses multi-layer neural networks	Handles complex data (image, speech, text)	High accuracy in pattern recognition	Image recognition, voice assistants
Generative AI	Creates new content (text, images, code)	Automates content and communication workflows	Human-like output generation	Chatbots, automated reporting
Robotic Process Automation (RPA)	Automates repetitive rule-based tasks	Executes automated decisions	Reduces manual effort	Invoice processing, data entry
Cloud Computing	Provides scalable computing infrastructure	Supports large-scale AI deployment	High scalability, remote access	SaaS AI platforms
Edge Computing	Processes data near source	Enables real-time automation	Low latency, improved privacy	Smart devices, autonomous vehicles
Internet of Things (IoT)	Connects smart devices and sensors	Supplies real-time operational data	Continuous monitoring	Smart cities, smart factories

5. Intelligent Automation Architecture and Workflow

Intelligent automation systems operate through structured architectures that integrate data acquisition, decision intelligence, execution mechanisms and continuous learning. Unlike traditional automation pipelines that follow linear workflows, intelligent automation architectures are cyclical and feedback-driven, allowing systems to adapt to changing conditions and improve performance over time [46]. This architectural shift enables automation to function as an ongoing capability rather than a one-time implementation.

5.1. Automation Lifecycle

The lifecycle of intelligent automation begins with data collection, where information is gathered from enterprise systems, sensors, user interactions and external data sources. Effective data collection ensures that automation decisions are based on comprehensive and real-time context. Data preprocessing, including cleaning and transformation, plays a critical role in maintaining reliability and accuracy of automation outputs ^[47].

The next stage involves decision intelligence, where machine learning models and analytics engines evaluate available information to determine appropriate actions. Decision intelligence enables automation systems to identify patterns, predict outcomes and recommend optimal strategies. This stage distinguishes intelligent automation from rule-based automation by incorporating probabilistic reasoning and adaptive learning ^[48].

Following decision-making, the execution stage translates insights into operational actions. Robotic process automation tools, APIs and orchestration platforms coordinate tasks across digital environments, ensuring seamless workflow execution. Execution mechanisms must be scalable and resilient to support large-scale automation initiatives across distributed infrastructures ^[49].

The final stage of the lifecycle is feedback and optimization, where system performance is evaluated using metrics such as accuracy, efficiency and user satisfaction. Feedback mechanisms enable continuous refinement of models and workflows, allowing automation systems to evolve alongside organizational requirements ^[50].

5.2. Human-in-the-Loop and Collaborative Automation

Despite increasing autonomy, human oversight remains essential in intelligent automation architectures. Human-in-the-loop models ensure that critical decisions involve human validation, particularly in high-risk domains such as healthcare, finance and cybersecurity. This approach balances efficiency with accountability and reduces the risk of unintended outcomes ^[51].

Collaborative automation extends this concept by positioning humans and automated systems as complementary contributors. While automation handles routine and data-intensive tasks, humans provide contextual judgment, ethical oversight and strategic direction. This collaborative framework enhances system reliability and supports user trust in automated processes ^[52].

Human-on-the-loop models represent an intermediate approach, where systems operate autonomously but allow human intervention when anomalies are detected. Such models are increasingly adopted in enterprise environments where scalability must be balanced with governance requirements ^[53].

5.3. Scalable Automation Frameworks

Scalability is a defining requirement of modern automation architectures. Scalable frameworks leverage cloud infrastructure, microservices and containerization to support distributed automation pipelines that can expand as demand increases. Modular design enables organizations to integrate new automation capabilities without disrupting existing workflows ^[54].

Another important aspect of scalable automation is interoperability. Intelligent automation systems must interact with legacy platforms, enterprise applications and emerging technologies. Standardized interfaces and orchestration layers facilitate seamless integration, ensuring that automation initiatives remain sustainable over time ^[55].

As automation ecosystems grow, governance mechanisms become essential for monitoring performance, enforcing policies and managing risk. Automation dashboards, audit trails and explainability features contribute to transparency and enable organizations to maintain control over increasingly autonomous systems ^[56].

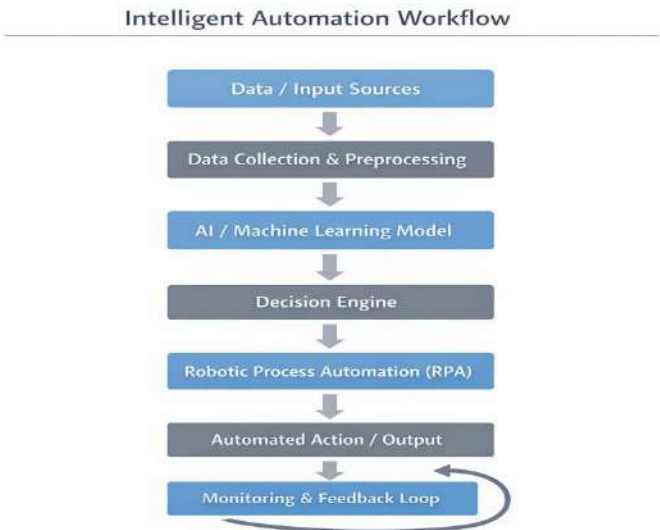


Fig. 2: Intelligent Automation Workflow

6. Real-World Applications of Smart Computing

The integration of intelligent automation and smart computing has enabled transformative applications across multiple sectors, where adaptive decision-making, real-time analytics and autonomous workflows are essential. These applications demonstrate how smart computing extends beyond theoretical frameworks to deliver measurable improvements in efficiency, reliability and service quality. By combining data-driven intelligence with automated execution, organizations can manage complex environments with reduced manual intervention and enhanced responsiveness^[57].

6.1. Healthcare Automation

Healthcare systems increasingly rely on intelligent automation to manage clinical workflows, patient data and operational logistics. Smart computing platforms enable automated appointment scheduling, predictive diagnosis support and real-time monitoring of patient conditions. Machine learning models analyze medical records and sensor data to identify risk patterns, assisting clinicians in making timely decisions while reducing administrative burden^[58].

Intelligent automation also improves hospital resource management by optimizing bed allocation, inventory control and staff scheduling. Integration with IoT devices allows continuous monitoring of vital signs, enabling proactive intervention and personalized care. These capabilities contribute to improved patient outcomes and operational efficiency, particularly in high-demand healthcare environments^[59].

6.2. Smart Cities

Smart computing plays a central role in urban management by enabling data-driven coordination of transportation, energy, water and public services. Intelligent traffic management systems analyze real-time sensor data to adjust signal timings and reduce congestion. Energy management platforms optimize power distribution by predicting demand fluctuations and supporting sustainable consumption patterns^[60].

In addition, smart governance initiatives leverage automation to improve citizen services, emergency response and infrastructure maintenance. Predictive analytics helps identify potential system failures, allowing preventive measures that reduce operational disruptions. These applications illustrate how smart computing supports resilient and sustainable urban ecosystems^[61].

6.3. Enterprise and Industry 4.0

In enterprise environments, intelligent automation enhances business process management by streamlining workflows, reducing errors and enabling data-driven decision-making. Automation frameworks integrate enterprise resource planning systems, customer relationship management platforms and analytics tools to create cohesive digital operations. This integration supports real-time insights and adaptive resource allocation across organizational functions^[62].

Industry 4.0 environments extend these capabilities into manufacturing and supply chain management. Smart factories employ predictive maintenance, automated quality control and autonomous logistics coordination to improve productivity and reduce downtime. The combination of IoT, edge computing and intelligent automation enables continuous optimization of industrial processes^[63].

6.4. Education and Digital Services

Educational institutions increasingly adopt smart computing solutions to support personalized learning, administrative automation and digital collaboration. Learning management systems use analytics to track student progress and recommend adaptive learning pathways, improving engagement and academic outcomes. Automation tools assist educators by managing assessments, scheduling and content delivery^[64].

Beyond education, digital service platforms leverage intelligent automation to enhance customer experience through chatbots, recommendation systems and automated support workflows. These applications demonstrate how smart computing enables scalable service delivery across diverse user populations^[65].

6.5. Cybersecurity Automation

Cybersecurity represents a critical application domain for intelligent automation due to the volume and complexity of modern threats. Smart computing systems analyze network activity, detect anomalies and initiate automated mitigation strategies in real time. Machine learning models enable early detection of potential breaches, reducing response time and minimizing impact^[66].

Automated security orchestration platforms coordinate incident response across multiple tools and environments, ensuring consistent and efficient

threat management. However, the increasing sophistication of automated attacks highlights the need for continuous adaptation and human oversight within cybersecurity automation frameworks^[67].

7. Challenges and Ethical Considerations

While intelligent automation and smart computing offer substantial benefits, their widespread adoption introduces a range of technical, organizational and ethical challenges. As computing systems gain greater autonomy, ensuring reliability, transparency and responsible use becomes increasingly important. Addressing these challenges is essential for sustaining trust in intelligent technologies and enabling their long-term integration into critical digital infrastructures^[68].

7.1. Technical Challenges

One of the primary technical challenges in intelligent automation is system scalability. As automation frameworks expand across distributed environments, managing computational resources, maintaining performance and coordinating multiple services become complex tasks. Scalable architectures must balance efficiency with reliability, particularly in environments that process large volumes of real-time data^[69].

Another major concern is system robustness. Intelligent automation relies heavily on data quality and model accuracy; inconsistencies in data can lead to incorrect decisions and operational disruptions. Ensuring robustness requires continuous monitoring, model retraining and validation mechanisms that can detect anomalies and maintain system stability^[70].

Integration with legacy systems also presents significant challenges. Many organizations operate heterogeneous infrastructures that were not designed for autonomous operation. Integrating intelligent automation into such environments requires standardized interfaces, interoperability frameworks and careful system redesign to avoid performance bottlenecks^[71].

7.2. Ethical and Social Implications

As automation systems assume decision-making responsibilities, ethical considerations become central to system design. Transparency and explainability are critical for enabling users to understand how automated decisions are made. Black-box models, while powerful, can reduce trust if their reasoning processes are not interpretable^[72].

Accountability represents another key concern. When automated systems

make incorrect or harmful decisions, determining responsibility among developers, organizations and users can be complex. Establishing governance frameworks and audit mechanisms is essential for ensuring responsible deployment of intelligent automation^[73].

Issues of bias and fairness arise when automation systems learn from historical data that may contain systemic inequalities. Without appropriate safeguards, automated decision-making can reinforce existing disparities. Ethical system design therefore requires diverse datasets, bias detection mechanisms and continuous evaluation^[74].

Data privacy and security are also critical considerations. Intelligent automation systems often process sensitive personal and organizational information, making secure data handling a fundamental requirement. Compliance with regulatory standards and implementation of privacy-preserving techniques are essential for maintaining user trust^[75].

Finally, intelligent automation has implications for the future of work. While automation improves productivity, it may alter workforce roles and require new skill sets. Organizations must address these changes through reskilling initiatives and human-centered automation strategies that emphasize collaboration rather than replacement^[76].

8. Future Trends in Intelligent Automation and Smart Computing

The evolution of intelligent automation and smart computing is expected to accelerate as advances in artificial intelligence, distributed infrastructure and human-machine collaboration reshape the capabilities of digital systems. Future computing environments will move beyond automation of tasks toward autonomous ecosystems capable of continuous learning, self-optimization and coordinated decision-making across multiple domains^[77]. These developments indicate a transition from intelligent tools to intelligent infrastructures that actively shape digital operations.

8.1. Autonomous and Self-Optimizing Computing Systems

A major future direction involves the development of autonomous computing systems that can manage resources, detect anomalies and implement corrective actions without direct human intervention. Self-optimizing infrastructure will enable computing environments to dynamically adjust performance parameters, allocate resources efficiently and anticipate potential failures before they occur^[78].

Such systems rely on reinforcement learning, predictive analytics and real-time monitoring to maintain operational stability. Autonomous computing is particularly relevant in large-scale cloud environments, industrial automation and smart city infrastructure, where manual management becomes impractical due to system complexity^[79].

8.2. Integration of Agentic and Generative Technologies

The integration of agentic computing and generative artificial intelligence represents another significant trend shaping intelligent automation. Agentic systems operate as goal-driven entities capable of planning and executing multi-step tasks, while generative technologies enable systems to create content, simulate scenarios and support decision-making processes^[80].

Together, these technologies allow automation frameworks to handle complex cognitive workflows such as dynamic service orchestration, personalized interaction and adaptive problem resolution. This convergence is expected to enhance the flexibility and intelligence of smart computing environments across sectors^[81].

8.3. Multimodal and Context-Aware Smart Environments

Future smart computing systems will increasingly rely on multimodal intelligence, integrating text, visual, audio and sensor data to achieve richer situational awareness. Context-aware computing will enable systems to interpret environmental signals, user behavior and operational conditions simultaneously, resulting in more accurate and responsive automation^[82].

This capability will support advanced applications such as intelligent healthcare monitoring, adaptive learning environments and autonomous industrial systems. By combining multimodal perception with automation workflows, smart computing will evolve into highly interactive and user-centric ecosystems^[83].

8.4. Governance and Sustainable Automation

As automation becomes more pervasive, governance frameworks will play a critical role in shaping its responsible development. Future intelligent automation systems are expected to incorporate built-in compliance mechanisms, ethical constraints and explainability features that ensure transparency and accountability^[84].

Sustainability is another emerging consideration. Energy-efficient computing architectures, green cloud infrastructure and optimized resource

utilization will become essential for reducing the environmental impact of large-scale automation. These developments highlight the need for holistic approaches that balance technological advancement with societal and environmental priorities ^[85].

9. Conclusion

The evolution of computer technology toward intelligent automation and smart computing represents a fundamental transformation in how digital systems operate, interact and deliver value across diverse domains. Traditional computing models, characterized by static workflows and heavy human intervention, are gradually giving way to adaptive environments capable of autonomous perception, reasoning and action ^[86]. This shift reflects the growing need for computing systems that can manage complexity, process real-time data and support decision-making in dynamic digital ecosystems.

This chapter has explored the foundational principles of intelligent automation, highlighting how the integration of artificial intelligence, robotic process automation, distributed infrastructure and analytics enables systems to perform tasks with increased efficiency and adaptability. The discussion of the smart computing paradigm emphasized the importance of layered architectures that combine data management, intelligence and infrastructure to create cohesive automation environments ^[87]. Emerging technologies such as cloud computing, edge computing, IoT integration and autonomous AI were identified as critical enablers of scalable automation frameworks.

The examination of real-world applications demonstrated that intelligent automation is no longer limited to experimental settings but has become integral to healthcare, smart cities, enterprise operations, education and cybersecurity. These applications illustrate how smart computing enhances operational resilience, improves service delivery and enables proactive decision-making. At the same time, the chapter addressed challenges related to scalability, interoperability, ethical governance and workforce transformation, underscoring the need for responsible implementation strategies ^[88].

Looking forward, future developments in autonomous computing, agentic systems and multimodal intelligence are expected to further expand the capabilities of smart computing ecosystems. The integration of governance mechanisms and sustainable computing practices will be essential to ensure that automation technologies remain trustworthy, transparent and socially

beneficial^[89].

In conclusion, intelligent automation and smart computing serve as core pillars of next-generation computer technologies. By enabling adaptive, scalable and collaborative digital environments, these paradigms have the potential to reshape how organizations design systems, manage processes and deliver intelligent services. Continued research and interdisciplinary collaboration will be critical for realizing the full potential of intelligent computing while addressing the technical and ethical challenges associated with increasing autonomy.

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16

CHAPTER

Advance Production Technology in Sprouting Broccoli

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Origin and Distribution

The word broccoli, from the Italian plural of broccolo, refers to “the flowering top of a cabbage”. Broccoli has large flower heads, usually green in color, arranged in a tree-like fashion on branches sprouting from a thick, edible stalk. The mass of flower heads is surrounded by leaves. Broccoli most closely resembles cauliflower, which is a different cultivar group of the same species. Sprouting broccoli is believed to have evolved from wild cabbage *Brassica oleracea* var. *oleracea* (syn. *Sylvestris*) in Southern Europe and the Eastern Mediterranean.

History:

Broccoli evolved from a wild cabbage plant on the continent of Europe. Broccoli has been considered a uniquely valuable food among Italians.

Broccoli was grown at Antwerp where it was taken to England by the sculptors Peter Scheemakers. Broccoli was first introduced to the United States by Italian immigrants.

Introduction:

Broccoli is one of the important members of the Cole group of vegetables, which has a common ancestry. It is considered to be the first to originate from wild cabbage *Brassica oleracea* var. *oleracea* (syn. *Sylvestris*), which is found growing wild along the Mediterranean Sea. It is mainly of two types, viz. green sprouting and purple heading broccoli. The head consists of closely packed mature differentiated flower buds in sprouting broccoli, immature differentiated flower buds in heading broccoli (winter cauliflower) and immature undifferentiated floral primordial in cauliflower. In the world, USA is the largest producer of broccoli followed by European countries. In India, it ranks at fourth place after cauliflower, cabbage and Knol-khol.

Composition and Uses

Composition

Sprouting broccoli is the most nutritive vegetable among the Cole crops because it contains relatively more quantities of vitamins and minerals, especially calcium and iron. In comparison with primary inflorescences, secondary inflorescences were characterized by higher levels of dry matter, total nitrogen, Vitamin C, chlorophyll, beta-carotene and carotenoids, and by lower levels of nitrates. Protein nitrogen levels were similar with primary and secondary inflorescences. The nutritive value is given below:

Table 1: Composition of sprouting broccoli (values are in 100 g edible portion)

Constituents	Content	Constituents	Content
Water (%)	89	Sodium (mg)	15
Protein (g)	3.6	Vitamin A (IU)	2500
Fat (g)	0.3	Thiamine (mg)	0.10
Carbohydrates (g)	5.9	Riboflavin (mg)	0.23
Calcium (mg)	103	Niacin (mg)	0.90
Phosphorus (mg)	78	Vitamin C (mg)	113
Potassium (mg)	382	Energy (kcal)	32
Iron (mg)	1.1		

Uses:

Broccoli is a nutritive green vegetable, which is most often boiled or steamed. It is served alone as well as in combination with other vegetables. It is eaten raw as salad and is liked in soups. In India, it is being used as a fresh vegetable, whereas, in USA and European countries, it is used in fresh as well as in frozen form.

Medicinal Properties:

Cruciferae plants (cabbage, kale, cauliflower, broccoli, watercress and radish) extracts showed highly significantly antioxidant capacities, which varied according to the agricultural techniques by which the vegetables were grown, and also to the vegetable part assayed within the same crop type. The anticancer potential of broccoli was estimated based on the known CD values of individual isothiocyanates. Its seeds have the anticancer potential. Other factors that can have negative impact on anticancer potential include the ESP- related conversion of glucosinolates to nitriles (rather than isothiocyanates) in some species, and the presence of ‘anti-nutritional’ glucosinolates.

- Has a tonic effect on the heart and helps indigestion.
- Has a soothing effect, promotes the flow of urine and relieves inflammation of the digestive tract.
- Scurvy and xerophthalmia, which is a persistent dryness of the cornea and conjunctiva due to decreased function of the tear glands.
- Anemia
- Leaves are cardio tonic and stomachic.
- Externally the leaves are made into a paste and used in gout and rheumatism.
- The decoction of the flowers has a soothing effect on the body, is diuretic or promotes the flow of urine, and is good for relieving inflammation of the digestive tract.
- Both the leaves and the flowers are recommended for scurvy and xerophthalmia.
- They are also recommended for anemia because of the abundance of iron they contain.

Climatic Requirement

The climatic factors had significant effect on yield, particularly associated on marketable head yield, however, among the Cole crops, broccoli is relatively tolerant of environmental stress. It thrives well in a cool moist weather and can withstand light frost. Flavor (sweet and fresh taste) improves with cooler temperatures because plant cells convert starch to sugars to protect plant against cold. Freezing temperatures cause injury to the developing heads. It is sensitive to higher temperatures as the heads become loose, the green buds develop into flowers, and the yellow petals are exposed over the head surface. Hot weather during heading leads to undesirable leafiness in the heads, and the heads develop so quickly that it becomes difficult to harvest at proper stage since temperature changes during growth and development influence various metabolic processes in plants.

In India, broccoli is grown during winter months in the plains, low, and mid hills of North (elevation up to 1500 m above mean sea level) and during summer months in higher hills, thereby making it as an off-season produce. Sprouting broccoli is an annual crop and does not require vernalisation or chilling temperature to enter into reproductive (bolting and flowering) phase, whereas, heading broccoli is a biennial and requires vernalization (temperature below 10°C) for heading (curd formation) and seed production. There was no effects of latitude on broccoli yields or head weights.

Soil Requirement:

Broccoli grows in almost all types of soils but well drained sandy loams rich in organic matter are ideal especially for early plantings. A pH range of 6.0 to 6.7 is preferred for optimum growth because this pH range ensures maximum nutrient availability and less incidence of club root disease. It has a relatively high requirement for molybdenum especially in acid soils with pH below 5.5, which can be corrected by liming or foliar fertilizer application. The micro nutrient boron is equally important in alkaline soil and the crop raised on such soil require the addition of borax or foliar sprays of boron.

Nursery Management

Broccoli is propagated by seeds, which are sown on raised beds of 3.0 x 1.0 x 0.15 m size. About ten nursery beds are required to produce the seedlings for planting an area of one hectare. A piece of land having preferably sandy-loam soil and plenty of sunshine is selected. It is ploughed

and prepared thoroughly. Well rotten FYM @ 20 – 25 kg and single super phosphate @ 200-250 g per bed are incorporated at the time of bed preparation. The nursery bed should be disinfected with 0.3% solution of Captan or Thiram or mancozeb or formaline 2% solution @ 5 liter per square meter. With formaline treatment, the nursery soil must be covered with polyethylene sheet for 48 – 72 hours, and thereafter, the soil must be exposed for 4-5 days so that the Formaline fumes get lost to the environment otherwise seed germination shall be impaired. Chlorpyrifos @ 2.5 ml per liter water may be used to protect the nursery from soil born insect-pests.

Seeds are sown in rows 5 cm apart at a depth of about 1.0 cm and covered with soil and dry grass mulch. A thatched structure is provided to protect the nursery from adverse weather conditions such as cold, heat and heavy rain. Polyethylene sheet cover can also be used except when protection from sun heat is required. Light but regular watering is required to ensure uniform germination and good growth. Grass mulch must be removed as and when the seeds start germination. Light weeding and hoeing is required. The nursery beds may be drenched with Mancozeb or Ridomil MZ or Captan @ 0.25 to 0.30% at weekly interval. Hardening of seedling must be started about a week before transplanting by reducing the quantity and frequency of watering.

Sowing/Planting Time:

The optimum time for sowing seeds in the nursery beds is from mid August to mid September. In the hills where the snowfall is rare or mild, seed sowing is carried out during July to August. In higher hills where the snowfall is severe, nursery sowing is done in March to April. Depending upon the prevailing weather conditions, the seedlings become ready for transplanting after 4-6 weeks of sowing. In agriculturally advanced countries direct seeding is practiced.

Manurial Requirement:

Broccoli needs fertilizers comparable with those applied in cauliflower. The nitrogen fertilizer requirement is rather more as liberal N- fertilizer side dressing after the harvesting of central head ensures a high yield of side shoots/spears. Besides the application of 20 – 25 t/ha of farmyard manure, it is advisable to apply nitrogen 150 kg, phosphorus 100 kg, and potash 50 kg per hectare. Entire dose of phosphorus and potash fertilizers and one third dose nitrogenous fertilizer are applied as basal application. The remaining

two-third dose of nitrogenous fertilizer is top dressed in two equal splits within 4-6 weeks of transplanting and just before the initiation of head.

The plants treated with nitrogen fertilizer had higher yield than the untreated control. The application of urea to foliage significantly increased the biomass of whole plants and the marketable yield. Like cauliflower, broccoli suffers from the deficiency of micronutrients especially molybdenum (highly acidic soils) and boron (under alkaline soils). Application of sodium or ammonium molybdate 1.0 kg and borax 10 – 15 kg/ha is recommended in such soils.

The foliar urea application significantly lowered the concentration of nitrates in broccoli heads compared with the plants not treated with urea. Additionally, foliar nutrition increased soluble sugar content. Moreover, the increase of ascorbic acid content in broccoli heads treated with urea was also observed. The nitrogen fertilizer treatments had significant effects on the contents of soluble sugars, phenols, ascorbic acid, dry matter, and nitrates. The reduced nitrogen form applied as a foliar treatment had significant effects on the nitrate reductase and nitrite reductase activities in broccoli heads. The activities of both enzymes were significantly associated with nitrate and ammonium ion contents and with the nitrate: ammonium ratio in broccoli heads. The nitrogen treatment supplemented with foliar application of urea had significant effects on the contents of nitrate and free amino acids. The foliar application of urea at 2% significantly increased the radical scavenging activity in broccoli both after harvesting and after storage, and total antioxidant activity slightly affected by the foliar fertilizer was high.

The yield attributing traits and marketable yield of broccoli increased linearly with increasing levels of NPK. Nutrient uptake and soil fertility build up followed almost similar trend. Application of NPK 15% + farmyard manure 20 t/ha registered the highest increase in the contents of organic carbon, available N, P, and K over their initial status.

Irrigation Requirement:

An even moisture supply is needed for broccoli seedlings to be established. To ensure adequate moisture requirement for proper vegetative growth and head formation, irrigation may be given at 1-2 weeks interval depending upon the soil type and prevailing weather conditions. Water stress during vegetative stage shall result in small sized heads and reduced yield.

Furrow irrigation at fortnightly intervals based on available soil

moisture depletion. There was improved growth, yield, and increased water use efficiency under drip irrigation compared to furrow irrigation. The highest broccoli yield of 25.14 t/ha was found under drip irrigation at 120% EPR with black plastic mulch, while the lowest yield of 9.22 t/ha was recorded in the furrow-irrigated plants. For the production of broccoli, it is recommended that irrigation be started when soil moisture falls below 55% vol. of ASW, followed by water application rates of either 14 or 28 mm.

Intercultural Operations:

Hoeing and Weeding:

Broccoli is a shallow rooted crop. Hence, deep hoeing and weeding should be avoided to keep the roots free from damage. Weeds are a problem during the first month after transplanting on account of more vacant space. Manual weeding and hoeing with hoe (khurpi) are done after two weeks of transplanting. Top-dressing with N fertilizer followed by earthing up is carried out after 4-5 weeks of transplanting, and thereafter, spot weeding can be done if required.

Mulching:

It is not a common cultural practice in broccoli. However, black polythene film and organic mulches (leaves, straw, hay, and crop waste) have been used in Cole crops to conserve moisture, suppress weeds, and add organic matter in the soil. Soil organic matter was significantly higher in the amended soils compared with no mulch plot. The concentration of napropamide in infiltration water from the soil treated with sewage sludge was similar to the no mulch plot but was lower than the napropamide in infiltration water from yard waste compost. Sewage sludge treatment resulted in maximum head weight, head diameter, stalk diameter and stalk length of spring broccoli. No mulch treatment resulted in maximum head weight for autumn broccoli but the maximum head diameter, stalk length and stalk diameter was recorded under the sewage sludge treatment.

Seed Rate:

Broccoli seed size is quite comparable with mid maturity group of Indian Cauliflower. About 300 – 400 g seed is required to raise seedling sufficient for transplanting an area of one hectare. For direct seeding, the seed rate is about four times higher (1200 – 1600 g/ha).

Planting:

The seedlings are transplanted on either flat or raised beds or on ridges in evening hours. Transplanting on raised beds or ridges avoids the adverse effects of stagnating rain water around the root zone. The size of broccoli heads and yields are affected by plant population density. With closer spacing, the yields are more, but the size of the main/central heads is reduced, and there is also less production of lateral heads or spears.

The maximum yield of individual heads for fresh market was obtained at a spacing of 45 x 30 cm using single plant transplants. The use of multiple plants per transplant plug decreases mean head weight and diameter. Under poly-house conditions, a spacing of 30x50 cm has resulted in highest yield of 21.06 t/ha. Depending upon the spacing, about 33,000 to 45,000 plants can be accommodated in an area of one hectare under open field conditions, whereas, about 60,000 plants per hectare can be adjusted under poly-house conditions.

Pest Control:

Weed control can be achieved with herbicides and a good crop rotation system. Broccoli competes fairly well with weeds, but should be kept weed free until plants reach the pre-heading stage. Many pre-transplants and post emergence herbicides are available for broccoli, depending on the specific weed problem and the broccoli growth stage. If infestation levels are mild, cultivation can minimize weed problems.

Insects are a major problem in broccoli production. Flea beetles, cabbage loopers, imported cabbage worms, diamond back moths, and aphids all can cause crop losses.

Several broccoli diseases can cause crop losses. Black rot, black leg, bacterial head rot, downy mildew, and *Alternaria* have been observed. Many of these diseases can be prevented by having a good crop-rotation and by using disease resistant varieties.

Harvest and Storage:

Broccoli is hand harvested. There are no mechanical harvesters for broccoli. Broccoli should be cooled with packed ice or a hydro-cooler immediately at 32°F and 95 to 100 percent relative humidity can be stored for 10 to 14 days. If broccoli is stored for long it will begin to lose its dark green color and firmness.

Depending upon the variety, season, and agro-climatic locations, the

heads are ready for harvest at different periods of the year. Central head constitutes the major portion of the total yield and should be cut off with sharp knife/sickle along with 15-20 cm stem. When the green buds are still small and tightly closed. Delay in harvest leads to the emergence of yellow petals in the head thereby rendering them unmarketable. Side heads/spears develop rapidly after the harvest of central head and their harvest continues for longer period in consonance with the prevailing temperatures. Over mature spears turn woody in texture and become unfit for consumption.

Presoaking in water before rinsing reduce the bacteria in broccoli. The flower section was more contaminated with *Listeria innocua* bacteria than the stem of broccoli.

Yield

The central head constitutes about 60 – 70% of the total yield but under optimum environmental conditions, the spears may constitute up to 50% of the total yield. Yield ranging from 7 – 20 t/ha has been reported from different regions of India.

Post-harvest Management:

Broccoli is highly perishable crop, as the respiration rate of freshly harvested heads/spears is very high. After removing the leaves from the cut-stem and head, the harvested produce is required to be hydro cooled by spraying or immersing the harvested produce in cold/chilled water. At room temperature, harvested produce can be kept for 2 – 3 days only. At low temperature (0°C and 95% relative humidity), it remains good for 10 -14 days. Wrapping of heads/spears in LDPE films keep the produce fresh and green when stored at room temperature. Broccoli heads and sprouts are tied in bunches of about 500 g and packed in waxed cartons or plastic crates. It should not be stored along with climacteric fruits (apple, pear, etc) which produce large quantities of ethylene which can cause yellowing of green buds. Highly perishable nature of broccoli, absence of refrigerated transport and inadequate low temperature storage at the terminal market are proving as a bottle necks in increasing acreage and production of broccoli in India.

Changes in isoperoxidases involved in chlorophyll degradation of stored broccoli florets decreased greatly after 2 days at 15°C, whereas, the contents in heat treated florets (50°C for 2 h) showed almost no change. The high density polyethylene film package greatly promoted the activation energy in broccoli, while delaying the respiration peak. The variation of colour

parameters was in accordance with chlorophyll content and yellowness degree in stored broccoli.

In broccoli, the deterioration occurred quickly in non-wrapped heads, manifested mainly by weight loss, yellowing, chlorophyll degradation, and stem hardening. Also, a rapid decrease in total antioxidants activity (TAA), ascorbic acid and total phenolic compound concentration was observed.

Physiological Disorders:

Internal tip Burning:

The leaf margins turn brown, and tip burn causes the leaves to be buried in the head. Broccoli requires low temperature for its normal growth but if it is grown at slightly higher temperature, the water requirement is increased, which is not fulfilled due to poor water movement within the plant, as a result, the leaf margins start burning.

Heat Injury:

In many parts of the world where the temperature is higher than the normal requirement, the broccoli produces rough heads with elongated peduncles. This disorder occurs only in heat sensitive varieties, so grow only heat resistant varieties in areas where temperature is high.

Hollow Stem:



It is due to the deficiency of boron and excessive use of nitrogen. Hollowness caused by boron deficiency is recognized as water soaked area, while that caused due to excessive use of nitrogenous fertilizer is distinguished by clear white stem with no sign of disintegration. The incidence of hollow stem occurs more at wide spacing. Only plants that produced heads with the largest mean weights and mean diameters exhibited

the disorder.

The use of multiple plants per transplant plug reduces the incidence of hollow stem. Hollowness due to boron deficiency can be cured by spraying borax at 0.1 -0.3%.

Insect-pests and Diseases:

The major insect-pests and diseases that affect the plant growth and the yield of broccoli are discussed below:

Insect-Pests:

Cut Worm (*Agrotis* spp.)

The grubs of cutworm are nocturnal in habit and cut the stem of the young transplanted seedlings just above the soil surface. This necessitates too much gap filling on one hand and uneven crop stand on the other.

Control:

- i) Use well rotten farmyard manure.
- ii) Add Chloropyriphos (20 EC) @ 2.0l/ha after mixing in about 25 kg of sand before transplanting the seedling.

Cabbage butterfly (*Pieris brassicae*)

The adult of this insect lays eggs in clusters on adaxial surface of leaves. Upon hatching, the young caterpillars start feeding on tender leaves, and in extremes cases, render the plants as Skelton. Such plants do not form head.

Control:

- i) Pick up infested leaves and destroy them.
- ii) Spray the crop with Malathion 0.1%, Nuvan 0.05%, or Endosulphan 0.15%.

Diamond Back Moth (*Plutella* spp.)

The female adult lays eggs in clusters on under surface of leaves. Upon hatching, the caterpillars start feeding on tender leaves, and in extremes cases, completely Skeltonize the leaves. Such plants do not form head.

Control:

- i) Pick the infested leaves manually and destroy them.
- ii) Spray the crop with Malathion 0.1%, Endosulfan 0.15%, or Nuvan

0.05%.

Aphids (*Brevicoryne brassicae* and *Myzus persicae*)

Aphids are troublesome in the sense that besides leaves they harbor within the dense bud clusters and suck the plant sap. The black sooty mould develops on the leaves where honeydew has been excreted thereby hampering the photosynthetic activity. This results in reduction of yield and quality of the produce.

Control:

- i) Spray the crop with plain water at high pressure.
- ii) Remove and destroy the affected plant portion in mild infestation.
- iii) Spray the crop with Endosulfan 0.15%, Malathion 0.1% or Nuvan 0.05%.

Diseases:

Damping off (*Pythium* sp., *Rhizoctonia* sp., *Fusarium* sp. and *Phytophthora* sp.)

It occurs mainly on seedlings in nursery beds. Softening of tissue takes place near the soil line and the seedlings fall off. High temperature, excessive soil moisture or water logging and poor soil aeration are the main factors that favor this disease.

Control:

- i) Provide proper drainage.
- ii) Follow long crop rotations strictly.
- iii) Avoid excessive irrigation.
- iv) Treat the nursery soil with fungicides, viz. Thiram or mancozeb or formaline.
- v) Treat the seed with Carbendazim/Thiram/Captan/mancozeb/Apron 2.5 g/kg of seed.

Downy Mildew (*Peronospora parasitica*)

Initially small brown coloured spots appear on the lower surface, which are soon covered with downy growth of fungus. The corresponding upper surface becomes chlorotic. Leaves may drop off pre-maturely.

Control:

- i) Follow long crop rotation.
- ii) Collect the infested disease debris and destroy them.
- iii) Follow prophylactic sprays of Indofil M-45 0.2%, Indofil Z-78 0.2%, or Ridomil MZ at 0.25%.
- iv) Treat the seed with hot water at 50°C for 30 minutes to kill the pathogens present on seed.

Stalk rot (*Sclerotinia sclerotiorum*)

The disease starts appearing with the earthing up of the crop. Initially the lower leaves touching the ground turn pale yellow and lose turgor. On the leaf petiole, small irregular dark brown to black necrotic lesions appear which are covered with white cottony mycelia growth of fungus. In advanced stages, the stem pith is infected followed by sclerotial development.

Control

- i) Follow long crop rotation with cereals especially paddy.
- ii) Spray the crop with carbendazim @ 0.05% at an interval of 10 days.

Black spot (*Alternaria* sp.)

Small, dark coloured, concentric, circular lesions up to 1.0 cm diameter appear on leaves. The head also gets affected. Disease is more common in seed crop.

Control

- i) Spray the crop with mancozeb or Ridomil MZ at 10 – 15 days interval.

Club root (*Plasmodiophora brassicae*)

It is more common in acidic soils in temperate regions. It is a soil born disease. Yellowing of foliage, flagging, and wilting of plants are the typical symptoms. Small, spindle-like, spherical, club-shaped swellings develop on roots and rootlets.

Control

- i) Follow long crop rotation with non-crucifers crops.
- ii) Liming of soil helps in reducing the disease incidence.

Black rot (*Xanthomonas campestris* pv. *campestris*)

Initially chlorotic lesions appear along the leaf margins which progress inwards forming V-shaped blotches. The veins and vein-lets turn black. In extreme cases, the heads rot.

Control:

- i) Follow long crop rotation with non-crucifers crops.
- ii) Treat the hot water at $50\pm 2^{\circ}\text{C}$ for 30 minutes dip in Streptocycline 100 ppm.
- iii) Spray with Streptocycline 0.01% or 100 ppm at monthly intervals.

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12

CHAPTER

Mineral Nutrient Disorders in Vegetable Crops

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Plants need the right combination of nutrients to live, grow and reproduce. When plants suffer from malnutrition, they show symptoms of being unhealthy. Too little or too much of any one nutrient can cause problems or disorders. Plant nutrients fall into two categories: macronutrients and micronutrients. Macronutrients are those elements that are needed in relatively large amounts. They include nitrogen, potassium, sulfur, calcium, magnesium and phosphorus. Micronutrients are those elements that plants need in small amounts (sometimes trace amounts), like iron, boron, manganese, zinc, copper, chlorine and molybdenum. Both macro- and micronutrients are naturally obtained by the roots from the soil. Plant roots require certain conditions to obtain these nutrients from the soil. First, the soil must be sufficiently moist to allow the roots to take up and transport the nutrients. Sometimes correcting improper watering strategies will eliminate nutrient deficiency symptoms. Second, the pH of the soil must be within a certain range for nutrients to be release-able from the soil particles. Third, the temperature of the soil must fall within a certain range for nutrient uptake to occur. The optimum range of temperature, pH and moisture is different for different species of plants. Thus, nutrients may be physically present in the soil, but not available to plants. A knowledge of soil pH, texture and history can be very useful for predicting what nutrients may become deficient.

Diagnosis of nutrient disorders and Visual Symptoms

Interpreting visual nutrient deficiency and toxicity symptoms in plants can be difficult and plant analysis or soil testing is necessary to confirm nutrient stress. Precautions in identifying nutrient stress symptoms include the following:

- It is important to know what a plant species looks like when it is healthy in order to recognize symptoms of distress, for example some plants were bred to have variegated patterns in the leaves when they are healthy.
- Many nutrient deficiencies may look similar. For instance, N and S deficiency symptoms can be very alike, depending upon plant growth stage and severity of deficiencies.
- If more than one problem is present, i.e. if water stress, disease, or insect pressure occurs simultaneously with a nutrient deficiency, or if two nutrients are deficient simultaneously, the typical symptoms may not occur.
- Multiple deficiencies and/or toxicities can occur at the same time. More than one deficiency or toxicity can produce symptoms, or possibly an abundance of one nutrient can induce the deficiency of another (e.g. excessive P causing Zn deficiency).

In addition to the above precautions, visual observation is also limited by time. Between the time a plant is nutrient deficient (hidden hunger) and visual symptoms appear, crop health and productivity may be substantially reduced and corrective actions may or may not be effective. Therefore, regular soil or plant testing is recommended for the prevention and early diagnosis of nutrient stress.

If visual symptoms are observed, record which crop(s) are affected, their location with respect to topography, aspect and soil conditions, a detailed description of symptoms and time of season that the symptoms first appeared. Affected field locations can be marked and monitored over time using either flagging or GPS readings. This information will be useful in preventing nutrient stress in subsequent years.

Deficiency symptoms

Visual symptoms of deficiency may take various forms, such as

- Stunted or reduced growth of the entire plant with the plant itself

either remaining green or lacking an over-all green colour with either the older or younger leaves being light green to yellow in colour.

- Chlorosis of leaves, either interveinal or of the whole leaf itself, with symptoms either on the younger and/or older leaves, or both (chlorosis is due to the loss or lack of chlorophyll production).
- Necrosis or death of a portion (margins or interveinal areas) of a leaf, or the whole leaf, usually occurring on the older leaves.
- Slow or stunted growth of terminals (rosetting), the lack of terminal growth, or death of the terminal portions of the plant.
- Reddish purpling of leaves, frequently more intense on the underside of older leaves due to the accumulation of anthocyanin.

Toxicity symptoms

When a nutrient is present in the soil in excess of plant's requirement, the nutrient is absorbed in higher amounts which causes imbalance of nutrients or disorder in physiological processes. Unlike deficiency symptoms, toxicity symptoms are less common.

Visual symptoms of toxicity may not always be the direct effect of the element in excess on the plant, but the effect of the excess element on one or more other elements. For example, an excessive level of potassium (K) in the plant can result in either a magnesium (Mg) and/or calcium (Ca) deficiency, excess phosphorus (P) can result in a zinc (Zn) deficiency and excess Zn in an iron (Fe) deficiency.

These effects would compare to elements, such as boron (B), chlorine (Cl), copper (Cu) and manganese (Mn), which create visual symptoms that are the direct effect of an excess of that element present in the plant. Some elements, such as aluminum (Al) and copper (Cu) can affect plant growth and development due to their toxic effect on root development and function.

Hidden hunger

In some instances, a nutrient element insufficiency may be such that no symptoms of stress will visually appear with the plant seeming to be developing normally. This condition has been named *hidden hunger*, a condition that can be identified by means of either a plant analysis and/or tissue test. A hidden hunger occurrence frequently affects the final yield and

the quality of the product produced. For fruit crops, abnormalities, such as blossomed rot and internal abnormalities may occur and the post harvest characteristics of fruits and flowers will result in poor quality and reduced longevity. A generalized visual leaf and plant nutrient deficiency and excess symptoms in horticultural crops are given in the following Table:

Generalized symptoms of nutrient deficiency and excess in crops

Nutrient	Symptoms
Nitrogen (N) Deficiency	Light green leaf and plant colour with the older leaves turning yellow, leaves that will eventually turn brown and die. Plant growth is slow, plants will be stunted and will mature early.
Excess	Plants will be dark green in colour and new growth will be succulent; susceptible, if subjected to disease and insect infestation; and subjected to drought stress, plants will easily lodge. Blossom abortion and lack of fruit set will occur.
Ammonium Toxicity	Plants fertilized with ammonium-nitrogen ($\text{NH}_4\text{-N}$) may exhibit ammonium toxicity symptoms, with carbohydrate depletion and reduced plant growth. Lesions may occur on plant stems, there may be a downward cupping of the leaves and a decay of the plants under moisture stress. Blossom-end rot of fruit and Mg deficiency symptoms may also occur.
Phosphorus (P) Deficiency	Plant growth will be slow and stunted and the older leaves will have a purple coloration, particularly on the underside
Excess	Phosphorus excess will not have a direct effect on the plant, but may show visual deficiencies of Zn, Fe and Mn. High P may also interfere with the normal Ca nutrition, with typical Ca deficiency symptoms occurring.
Potassium (K) Deficiency	On the older leaves, the edges will look burned, a symptom known as scorch. Plants will easily lodge and be sensitive to disease infestation. Fruit and seed production will be impaired and of poor quality.
Excess	Plants will exhibit typical Mg and possibly Ca deficiency symptoms due to a cation imbalance.
Calcium (Ca) Deficiency	The growing tips of roots and leaves will turn brown and die. The edges of the leaves will look ragged as the edges of emerging leaves stick together. Fruit quality will be affected with the occurrence of blossom-end rot on fruits.
Excess	Plants may exhibit typical Mg deficiency symptoms and when in high excess, K deficiency may also occur.
Magnesium (Mg) Deficiency	Older leaves will be yellow in colour with interveinal chlorosis (yellowing between the veins) symptoms. Plant growth will be slow and some plants may be easily infested

	by disease.
Excess	Results in a cation imbalance showing signs of either a Ca or K deficiency.
Sulfur (S) Deficiency	A general overall light green colour of the entire plant with the older leaves being light green to yellow in colour as the deficiency intensifies
Excess	A premature senescence of leaves may occur.
Boron (B) Deficiency	Abnormal development of the growing points (meristematic tissue) with the apical growing points eventually becoming stunted and dying. Flowers and fruits will abort. For some grain and fruit crops, yield and quality is significantly reduced
Excess	Leaf tips and margins will turn brown and die.
Chlorine (Cl) Deficiency	Younger leaves will be chlorotic and plants will easily wilt. For wheat, a plant disease will infest the plant when Cl is deficient.
Excess	Premature yellowing of the lower leaves with burning of the leaf margins and tips. Leaf abscission will occur and plants will easily wilt.
Copper (Cu) Deficiency	Plant growth will be slow and plants stunted with distortion of the young leaves and death of the growing point.
Excess	A Fe deficiency may be induced with very slow growth. Roots may be stunted.
Iron (Fe) Deficiency	Interveinal chlorosis will occur on the emerging and young leaves with eventual bleaching of the new growth. When severe, the entire plant may be light green in colour.
Excess	Bronzing and tiny brown spots on the leaves.
Manganese (Mn) Deficiency	Interveinal chlorosis of young leaves while the leaves and plants remain generally green in colour. When severe, the plants will be stunted.
Excess	Older leaves will show brown spots surrounded by a chlorotic zone and circle.
Molybdenum (Mo) Deficiency	Symptoms will frequently appear similar to N deficiency. Older and middle leaves become chlorotic first and in some instances, leaf margins are rolled and growth and flower formation are restricted.
Excess	Not of common occurrence.
Zinc (Zn) Deficiency	Upper leaves will show interveinal chlorosis with an eventual whiting of the affected leaves. Leaves may be small and distorted with a rosette form.
Excess	Fe deficiency will develop.

When a nutrient level falls, plants show characteristic symptoms of deficiency. These symptoms, through vary with crop, have a general pattern. These are generally masked by diseases and other stresses and so need careful and patient observation on more number of plants for typical symptoms. The deficiency symptoms appear clearly in crops with larger leaves.

Identification of Deficiency Symptoms

The deficiency symptoms can be distinguished based on the

- (1) Region of occurrence,
- (2) Presence or absence of dead spots and
- (3) Chlorosis of entire leaf or intervenial chlorosis.

The region of appearance of deficiency symptoms depends on mobility of nutrient in plants. The nutrient deficiency symptoms of N, P, K, Mg and Mo appear in lower leaves because of their mobility inside the plants. These nutrients move from lower leaves to growing leaves thus causing deficiency symptoms in lower leaves. Zinc is moderately mobile in plants and deficiency symptoms, therefore, appear in middle leaves. The deficiency symptoms of less mobile elements (S, Fe, Mn and Cu) appear on new leaves. Since Ca and B are immobile in plants, deficiency symptoms appear on terminal buds. Chlorine deficiency is less common in crops.

The symptoms that appear on old leaves can be further distinguished based on the presence or absence of dead spots.

Without Dead Spots: The characteristic deficiency symptom of nitrogen is uniform yellowing of the leaves including the veins. The leaves become stiff and erect especially in cereals. The leaf may detach after a little forceful pull in extreme deficiency in dicotyledonous crops. Cereal crops show characteristic 'V' shaped yellowing at the tip of lower leaves. In phosphorus deficiency, leaves are small, erect, unusually dark green with a greenish red, greenish brown or purplish tinge. The rear side develops bronzy appearance. Magnesium deficiency also causes yellowing, but differs from that of nitrogen. The yellowing takes place in between the veins and the veins remain green. The leaf is not erect. The leaf detaches very easily and may be shed by blowing wind. Necrosis (death of tissues) occurs in extreme cases only in the margins.

With Dead Spots: In potassium deficiency, yellowing starts from tips

or margins of leaves extending to the center of leaf base. These yellow parts become necrotic (dead spots) very soon. There is sharp difference between green and yellow and yellow and necrotic portions. The dead spots appear particularly on margins and tips. Molybdenum deficiency causes translucent spots of irregular shape in between the veins of leaves. These spots are light green, yellow or brown in colour. The affected spots are impregnated with resinous gum which exudes from rear side of the leaf from the reddish brown spots.

These symptoms may be spread over entire leaf or the veins may remain green.

Veins Remaining Green: Veins remain green in iron and manganese deficiency. In iron deficiency, the principal veins remain conspicuously green and other portions of the leaf turn, yellow tending towards whiteness. Under severe deficiency, most part of the leaf becomes white. In manganese deficiency, the principal veins as well as the smaller veins are green. The interveinal portion is yellowish, not tending towards whiteness. Dead spots also appear at a later stage. There is a chequered appearance to the leaf.

Veins not Remaining Green: The leaf becomes yellowish due to sulphur deficiency, but looks like nitrogen deficient leaf. The leaf is small and the veins are paler than interveinal portion. No dead spots appear. Plant does not lose the lower leaves as in the case of N deficiency. In copper deficiency, leaf is yellowish tending towards whiteness. In extreme deficiency, chlorosis of veins occurs and leaf loses luster. Leaf is unable to retain its turgidity and hence, wilting occurs. Leaf detaches due to water soaked conditions of the base of petiole.

Calcium and Boron Deficiency on Terminal Buds

The deficiency symptoms of Ca and B are many times seen on new leaves. However, it is easy to recognize their deficiency symptoms on the terminal buds or growing points than on new leaves. In calcium deficiency, the bud leaf becomes chlorotic white with the base remaining green. About one-third chlorotic portion of the tip hooks downward and becomes brittle. Death of terminal bud occurs in extreme cases. Boron deficiency causes yellowing or chlorosis which starts from the base to tip. The tip becomes very much elongated into a whip like structure and becomes brownish or blackish brown. Death of the terminal bud occurs in extreme cases.

Common Mineral Nutrient Disorders in Vegetable Crops

Deficient element	Disorder	Crop	Symptoms
Calcium (Ca)	Blossom-end rot	Tomato, Pepper	Decay of the blossom-end of the fruit
Boron (B)	Brown heart	Turnip	Rotting of centre of root
	Hollow stem	Cauliflower, Cabbage	Rotting of centre of stem
	Hollow heart	Potato	Formation of cavity near the tuber centre
Manganese (Mn)	Marsh spot	Pea	Brown area in centre of seed
Molybdenum (Mo)	Whiptail	Cauliflower	Reduction or suppression of leaf Blades

Blossom end rot (BER)



Blossom end rot occurs mainly during hot weather conditions. Fruits are affected in their early stages of development (10-15 days after fruit set). Blossom-end rot occurs because there is a problem of calcium transport, not getting enough calcium to the fruit. This results in the collapse of certain tissues in the fruit, demonstrated as BER. The reason they rot is because of low calcium in the cell walls. Factors that favor BER are directly related to limited calcium uptake and transport to the fruit, like high salinity, high temperatures and high growing intensity and water shortage.

Brassica Hollow Stem (Heart)



Hollow stem is a physiological disorder in cabbage, cauliflower and broccoli - frequently linked to calcium and boron deficiency or over-supply of nitrogen. Fast growing conditions often brought on by heavy rainfall and warm weather after a cold period - tend to favor the occurrence of hollow stem. During these conditions, growth is rapid, but levels of both calcium and boron will be diluted in new tissues. As a result, cell walls lack strength and elasticity, leading to cell breakdown and cracking of stems.

Stem brassicas have hollow stems due to tissue cracking accompanied by a browning, corking or rotting of the damaged pith tissue. Brassicas are tolerant to high levels of boron and toxicity is rare. Calcium and boron supplies are essential for the production of strong but elastic cell walls and to minimize crop disorders. Both nutrients have a key role to play in minimizing cracked stems, hollow heart and in providing good long term storage characteristics.

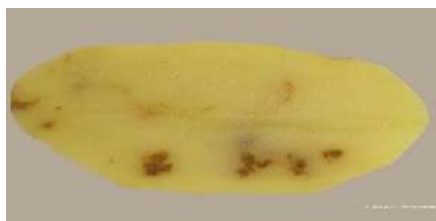
In addition, too much forced growth through over-application of nitrogen - especially if this is out of balance with calcium and potassium availability - may create an inadequate supply of these elements and result in hollow stem.

Whiptail in Cauliflower



Whiptail disorder is caused due to deficiency of molybdenum. In young plants the deficiency symptoms are chlorosis of leaf margins and the whole leaves may turn white. The leaf blades do not develop properly. When the deficiency is severe, only the midribs develop. This condition is commonly known as 'Whiptail'. The growing point of the plant is also deformed which prevents the curd development. The deficiency of molybdenum generally occurs when the soil pH is below 5.5 in acid soils.

Internal rust spot in potato



Plants that are deficient in calcium are spindly with small, deformed leaflets developing chlorotic margins which subsequently turn necrotic. However, the most common symptom of a shortage of calcium is internal rust spot in the tuber. This is scattered brown necrotic flecks sometimes in the vascular ring but also within the pith. The scattered and irregular flecks distinguish it from Hollow Heart, which is central to the tuber. This syndrome is most frequent on light, acidic soils where irrigation is not applied or is sporadic. It has been found on other soil types even where soil calcium levels are adequate. Some cultivars are particularly susceptible.

Hollow Heart Potato



Although many people refer to hollow heart as a disease of potato, there is no infectious agent involved; this problem is purely environmental. It is difficult to differentiate between the potatoes with hollow heart from the perfect potatoes until we cut them. Hollow heart in potatoes manifests as an irregularly-shaped cavity in the potato's heart — this empty area may have a brown discoloration, but that isn't always the case. The cavity is usually angular and the walls of the cavity are frequently thickened and of a light brown colour. Prior to the cavity forming, the central cells appear water-soaked or translucent. Sometimes a brown diffuse area known as brown spot develops as a precursor to cavity development. Occasionally, bacteria or fungi invade the cavity and rot the tuber from the inside. Hollow heart occurs mainly in large tubers of ware or table potato crops but early symptoms

(brown spot) can occur in smaller tubers.

When environmental conditions fluctuate rapidly during potato tuber development, hollow heart is a risk. Hollow heart is a physiological disorder and develops where tuber growth is unusually rapid. Frequently it will occur where conditions for rapid growth follow a period of slow growth, such as where rainfall follows a period of moisture stress. Hollow heart is more common where plant spacing is uneven and few large tubers form. Varieties vary in their propensity to develop hollow heart.

Marsh Spot in pea



Manganese deficiency can develop at any time during the early stages of crop growth and foliar symptoms can begin to show during the pre-flowering, vegetative stage. Growth appears pale in colour and closer observation of the leaves and stipules reveals a general chlorosis which is interveinal. The margins of the leaves are also chlorotic and, in time, small brown speckles develop on the leaf surface. The deficiency can show up in patches over the field or it may follow areas of compaction or soil structure differences, especially in alkaline soils. The most seriously affected crop is peas. Where plants develop manganese deficiency early on, seeds can develop an area of granulation or necrotic spot in the centre of the cotyledons. This symptom is known as marsh spot and was first described in peas grown in the Romney Marsh area of Kent in southern England. The spot may be discrete or extensive and may affect the embryonic plumule. When marsh spot affected seeds are germinated, such damage to the plumule gives rise to abnormally developed seedlings.

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13

CHAPTER

Production Technology in French Beans

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(Syn: Snap bean, String bean, Kidney bean, Haricot bean, Fresh bean)

(*Phaseolus vulgaris* L.)

Chromosome no: $2n = 22$

Introduction

French bean is an important cool season legume vegetable grown for its tender pods, shelled green beans and dry beans (*Rajmah beans*). In western countries, processed pod consumption is quite high. It is grown for the tender green beans and dry seeds. The pods are slender, 10-25 cm long, straight or slightly curved with prominent beak. Seeds are kidney shaped, elongated and white, red, purple or blackish in colour or mottled. The vegetable is in great demand in cities and is grown both commercially and in home gardens. Its major area is confined to hills, where it is grown for green pods. Punjab, Jammu and Kashmir, Gujarat, Karnataka, Tamil Nadu, Uttar Pradesh and Himachal Pradesh are the main states where it is being cultivated on large scale. In India, it is grown in area of 4268 hectare with annual production of 24778 tonnes. Dry grains are an excellent source of cheap protein and many varieties contain 22-23% protein. Hundred grams of edible fresh pods contain 91.4% water, 1.7% protein, 0.1% fat, 0.5% mineral matters, 4.5% carbohydrates, 50 mg Ca, 28 mg P and 1.7 mg Fe. Its 100g dry seeds contain 9.6% water, 24.9% protein, 0.8% fat, 3.2% mineral matters, 60.1% carbohydrates, 60 mg Ca, 433 mg P and 2.4mg Fe. In India, it is mostly

grown for fresh consumption, while in USA it is grown for processing in large quantities.

Origin and Taxonomy: Central America.

Following four species are under cultivation in New World

- *Phaseolus vulgaris* – French bean
- *P. coccineus* – Runner or Scarlet bean
- *P. lunatus* – Lima bean, Butter bean or Madagascar bean
- *P. acutifolius* var. *latifolius* – Tapery bean

All the given species are diploids with $2n=22$ and self-pollinated except *P. coccineus*, which is cross-pollinated. French bean, the most important species under *Phaseolus*, is originated in central and South America.



P. vulgaris



Phaseolus coccineus



Phaseolus acutifolius



White Tepary Beans

Health benefits of beans:

- Protein. Protein is a vital nutrient that plays a key role in maintaining and repairing the body.
- Folate. Beans contain several vital nutrients, including folate.
- Antioxidants.

- Heart health.
- Reduced risk of cancer.
- Diabetes and glucose metabolism.
- Preventing fatty liver.

Popular Varieties/Hybrids:

There are three types of French bean viz., bush type with short internodes, semi-pole type with longer internodes than those in bush type and the pole typed having longer internodes than that of semi pole type.

French bean cultivars are classified into string less type based on the extent of fiber in the pod and into bush type and pole types according to the growth habit.

There are a large number of French bean cultivars. It classified cultivars are as follows:

- Snap beans-for vegetable pods
- Green shell beans-used in the green shelled condition
- Dry shell beans – used in the dry state (Field beans)

Each group is further divided into climbing (Pole) and dwarf types.

Some of the important snap bean cultivars are as follows:

- ✓ The flat types are bountiful, plentiful, green ruler, golden ruler
- ✓ The oval types include Pusa Parvati, Contender, Premier, Tender Green, King Green etc.
- ✓ The pole type includes Blue Lake, Kentucky Wonder

Bush Type

Contender: It is an introduction from USA. It takes about 50-55 days for first picking. Pods are green round, 13-14 cm long, stringless, yields 8 to 9.5 t/ha. Tolerant to powdery mildew and mosaic.

Premier: Pods 11-13 cm long, ready for harvest in 55-60 days. Less susceptible to wilt and mosaic, average yield 75-90 q/ha.

Pusa Parvathi: Released from IARI, Katrain. It is developed through X-ray irradiation of the American variety 'Wax pod'. Early bearing, stringless, yield 8-8.5t/ha. Resistant to mosaic and powdery mildew.

Arka Komal: A pure line selection from IIHR-60 (Collection from Australia). Plants erect and bushy, Photo insensitive Flat, green straight pods. Seeds light brown, oblong and large. Good transportation and cooking qualities. Seed yield 1500 kg./ha Duration 70 days. Pod Yield 20 t/ha.

Arka Sharath: It has round, string less, smooth pods suitable for steamed beans. Pods are crisp, fleshy with no parchment and perfectly round on cross section. Plants are bushy and photo insensitive and it is suitable for both *kharif* and *rabi* seasons. It gives maximum number of pods per plant (44.5) compared to checks. It has high pod yield potential of 18.5 t/ha in 70 days.

Arka Suvidha: Suitable to grow throughout the year. Early stringless and first picking 70 days after sowing, yield is about 9t/ha.

Arka Bold: Grown throughout the year. Pods are flat 16 cm long, stringless, resistant to rust, ready for picking 70 days after sowing. Yield is about 8t/ha.

Bountiful: Introduction from USA. Pods borne in clusters on the main stem. Average yield is 10-12t/ha.

Jampa: It is a Mexican variety. Plants are shy in tillering habit. Early variety, pods are flat, smooth, pale green in colour. The seeds are black, smooth and small in size. Yields around 8-9t/ha. Highly resistant to wilt disease and withstand warmer conditions.

V.L. Bauni Bean 1: It has been developed by Vivekananda Parvathiya Krishi Anusandhanashala (VPKAS), Almora, Uttaranchal. It produces non stringy, long, fleshy green pods. It does well in the hills but suffers badly from mosaic.

Pant Anupama: Released from GBPUAT, Pantnagar. It is recommended for hills of Uttaranchal and UP. Prolific bearer, round, straight and green pods, first picking is done at 55-65 days after sowing. Yields 9t/ha. Moderately resistant to mosaic virus and rust.

Pant Bean-2: Released from GPPUAT, Pantnagar. It is cross between Turkish x Brown Contender. Pods are flattish round, non-stringy, yields around 9t/ha. Moderately resistant to mosaic and rust.

YCD-1: Released from TNAU, Yercard. Pods slightly flat, seeds bold, attractive, dark purple in colour. It is resistant to root rot, rust, YVMV and anthracnose. Yields 9.5t/ha in 105 days.

Arka Anoop: It is a pedigree selection from the cross Arka Bold x Arka Komal, plants are bushy, photo insensitive, long pods (17-18cm), resistance to rust and bacterial blight. Yield is 15t/ha.

Phule Surekha: Developed at MPKV, Rahuri. Suitable for all seasons, pods are 9-10 cm long, resistance to anthracnose, yellow mosaic and wilt. Yield is 15 t/ha.

Pole Types:

Kentucky Wonder: It was introduced to India from USA. Plants are tall, creeping or viny habit, pods ready for harvesting 60-65 days, 4-5 pods/cluster, pods long, flattish, stringless, seeds light brown yields 100-125 q/ha.

SVM-1: It is developed through hybridization between *P. vulgaris* var. Contender x *P. Multiflorus* var. PBL 257. Pods are green, round, stringless, 13-14cm long, 5-10 seeds/pod. Ready for harvest at 65-75 days after sowing. Average yield is 105-250 q/ha. Recommended for hill area. Resistant to angular leaf spot.

Lakshmi: It is a cross between Contender x Local (Pole) type. Pods formed in clusters of three, 13-14 cm long, stringless, ready for picking in 65-70 days. Average yield is 120-140 q/ha. Tolerant to angular leaf spot.

TKD1: It is a hybrid derivative of a cross between two pole types, viz., Selection and PV118. Green tender pods harvested from 60 days after sowing. Pods are long, flat, low fiber content. Yields 5-6t/ha.

KKL1: It is also known as Moringa bean. Developed at TNAU, Kodaikanal. Best suited for elevation 1800-2400m. It has a potential yield of 7t/ha. Pods or 3t/ha of grains.

Pusa Himlata: Developed at IARI, Katrain. Pods are straight, 14cm long; light green, stringless with white seeds.

Azad Rajmah-1: Developed at CSAUAT, Kanpur. Pods are highly attractive, smooth, stringless. Yields about 7.5-8t/ha.

Climate

French bean requires mild warm weather for good yield. It is a day neutral crop except some few semi-pole varieties which are short day types. It is sensitive to frost and very high temperature. The optimum temperature ranging between 15-25°C. It is also sensitive to high temperature and high

RH. The plants shed their blossom or young pods in very hot or rainy weather.

Soil:

French bean is grown in variety of soils ranging from light sandy soils to clay soils but it can withstand water logging. The optimum soil pH is between 5.3 and 6.0. High moisture content and high nitrogen caused delay in maturity.

Season:

There are two main growing seasons for French bean in the plains of India. The first sowing is done during July-September and May even extended up to September. The second sowing is early spring that is between January to February. In hilly regions seeds are sown on the month of March-May.

Cropping System:

Being a leguminous crop, it fits well in any crop rotation. Red kidney varieties are preferred to white seeds in heavy rainfall areas. Such varieties also fit well in crop rotation with wheat. It can also be grown as an intercrop in widely spread cucurbits till the main crop begins to throw veins.

Land preparation: The soil should be ploughed; clods are broken and weeds are removed and brought to fine tilth by shallow cultivation.

**Seed Rate**

The seed rate varies considerably depending on the variety, soil and climatic conditions. The rate for bush varieties is 60-65 kg/ha while it is 25-30kg/ha for pole varieties. Inoculation of seed with rhizobium species facilitates quick nodulation on the roots, and help in the fixation of atmospheric nitrogen.

Sowing

The seeds of bush beans are sown in rows 30-45 cm apart and 10-15 cm away from seed to seed whereas pole beans are in the spacing's of 60 cm to 100 cm between rows and plant to plant 30 cm. The depth of the sowing shall be 2 cm. To avoid fungal infection, treat the seed with *Rhizobium phaseoli* @ 30 g/kg of seed.

Nutrition

Before sowing, at the time of ploughing apply FYM @ 25 t/ha. Although French bean is a legume, it responds well to the application of nitrogen. Application of 63 kg N, 100 kg P₂O₅ and 75 kg K₂O/ha is recommended. Half of the N along with entire dose of P and K fertilizer should be applied at the time of sowing. Remaining half of N should be applied at the time of earthing up after 3rd week of sowing. Spraying micronutrients improves the quality besides increasing yield.

Irrigation

Prior to sowing the plots are irrigated and after 2-3 days when the soil is in moist condition seeds are sown along the sides of the ridges. Light irrigation is given after 2nd to 3rd day after sowing. French bean is a shallow rooted crop. Water stress has marked influence on yield and quality of pods. About 6-7 irrigations would be required at regular intervals. Depending upon the atmospheric conditions, the amount of irrigation will be decided. The crop should be irrigated at an interval of one week. Excess water reduces nodule formation and ultimately growth of plant.

Weed control

A pre sowing application of fluchloralin @ 2 l/ha checks the weed growth. At least two hand weedings are required before earthing up. Shallow cultivation during the early stages of crop is necessary to check the weeds and to facilitate earthing up. At the later stages of the crop growth, the weeds are kept under check due to the thick canopy of the crop.

Pinching out and staking

French bean needs stake in order to obtain high yield. Support the 3-week-old seedlings using stake with 1.8 m - 2.4 m in length. Other method used to support the French bean is trellis system. Join 2 sticks nearby to the wire to form trellis.

Use of Growth Regulators

Application of growth regulators improves the plant growth, flowering fruit set and pod yield in French bean. Plant regulators like PCPA @ 2ppm, L-naphthyl acetamide or B-naphthal acetic acid at 5-25ppm shown favourable effect on fruit set. GA3 sprayed at 50-200 ppm proved effective in improving the crop growth. Paclobutrazol at 150 ppm can be used for increasing yield and suppressing vegetative growth of pole type varieties of French bean.

Harvesting and Yield

The crop is ready for first harvest in about 45 days after sowing. The green pods are to be picked when they are immature and fully grown but still tender. As the harvest is delayed, the total yield increases but the quality falls rapidly due to over maturity of pods, fiber development and rough surface. The yield of tender pods varies from 8-10t/ha in bush varieties and 12-15 tons in pole types.

Marketing

After harvesting, pods kept in shade to avoid evaporating. Over matured, diseased and damaged pods should be sort out. Pods may be packed in baskets/gunny bags and transport it to the market.

Storage

The pods stored for 2-3 days in summer and 4-6 days in winter at room temperature. In cold storage, pods can be stored at 2 – 4 degrees Celsius with 60-70 % RH for about 15-20 days.

Seed Production

It is self-pollinated crop. Even then an isolation distance of 50 and 25 m should be maintained for Foundation seed and certified seed respectively. First rouging before pod set on the basis of foliage and flower characters, second at the time of pod formation on the basis of pod characters. Completely dried pods are harvested and kept in sunlight for drying. Threshing and cleaning can be done by hand or thresher. The average seed yield is about 15-20q/ha.

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CHAPTER

Green-Synthesized GHAP Nanoparticles: Promising Tools for Cancer Therapy and Bone Regeneration

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Abstract

The research emphasizes the integration of nanotechnology and biosciences for medicinal purposes specifically at the cellular level. The focus is on promoting the use of green synthesis of nanoparticles as a cost-effective and environmentally friendly alternative to chemical approaches. We used a microwave technique using Pomelo fruit extract to produce GHAP in an eco-friendly manner. The produced GHAP nanoparticles were analysed using techniques such as XRD, SEM, FTIR and HRTEM. The synthesized GHAP exhibited pronounced cytotoxicity on two human cancer cell lines (MCF-7 and MG63) in *in vitro* assays. This indicates the

possibility of using this for cancer treatment. The research also examined the relationship between the GHAP and MC3T3-E1 cells (bone-like cell). The *in vitro* viability tests demonstrated excellent biocompatibility, indicating that the nanoparticles did not exhibit any detrimental effects on bone-like cells. Crucially, the DAPI staining revealed that osteoblasts adhered to the GHAP, indicating its potential for use in bone bonding applications. In summary, the research indicates that the synthesized GHAP has potential for use in both cancer treatment and bone regeneration.

Keywords: Green synthesis; Cancer; Biocompatibility; Nanoparticles.

Introduction

Hydroxyapatite (HAP) is a calcium (Ca)/phosphate (P) (Ca/P) composite that is existing in the crystalline phase of the hardest tissues of mammals ^[1]. The cytocompatibility and high affinity of HAP for proteins and DNA are essential characteristics that make it suitable for biomaterials. These properties support biological processes and enable specific functions ^[2]. At present, HAP-based biomaterials, including as coatings and scaffolds, are extensively used in the medical field for repairing and regenerating dental and bone tissue. These bioactive materials demonstrate their flexibility and efficacy in medical applications. The extraordinary mechanical qualities found in human bone are attributed to the existence of bicarbonate hydroxyapatite (HAP) nanocrystals. These nanocrystals play a crucial role in the combined structure of bone tissue, providing strength and durability. Compared to larger or smaller quantities, nanoscaled hydroxyapatite (HAP) offers several significant advantages. These benefits include greater durability and the toughness in bioceramics, improved compatibility with bone systems, a greater capacity for adsorbing medication, DNA and protein molecules and outstanding dissolution in acids ^[3]. Consequently, nanoscale HAP is an adaptable and valuable substance for a wide range of medical applications.

Recent progress in synthesizing hydroxyapatite (HAP) has included the use of many techniques such as biomimetic accumulation, numerous formulations, thermal processes, sol-gel methods, microwave irradiation, ultrasonication, electrophoretic deposition and electrodeposition ^[4-6]. The microwave irradiation procedure is preferred due to its uniform mixing at a molecular level, high-quality product, lower synthesis temperature and nanoparticle generation capability. The microwave irradiation synthesis of hydroxyapatite (HAP) usually results in a superstructure consisting of small

grains with a variety of crystallographic particles, varying in size from nanometres to submicron's ^[7]. This demonstrates the high level of control and homogeneity that can be achieved using this process. Reports indicate that these crystals effectively improve the strength and interaction between artificial and natural bones in various settings ^[8]. To produce hydroxyapatite (HAP) using the microwave irradiation process, a specific Ca/P molecular ratio of 1.67 is necessary in the end product ^[9]. Several factors, such as the dimensions and morphology of the crystals, the presence of impurities, the composition and sequence of precursor reagents, the synthesis method, the concentration and order of mixing reagents, the p^H , the temperature and influence the physiological activity of Ca/P derived substances ^[10]. Chemical synthesis procedures produce toxic chemicals that adhere to surfaces and may have adverse effects in medical applications.

Using plant extracts in the production of HAP particles offers dual advantages: it is environmentally friendly and suitable for pharmaceutical and biological applications. This underscores the sustainable and adaptable character of these synthesis methodologies ^[11]. Moreover, the green template synthesis seems to surpass chemical and physical methods due to its cost-effectiveness, eco-friendliness, scalability for large-scale synthesis and lack of need for hazardous chemicals, high pressure, temperature, or energy ^[12]. Several research have examined the anticancer properties of HA nanoparticles on cancer cell lines ^[13-15]. Consequently, this work utilizes the green chelating agent as a template to synthesize HAP powders, utilizing plant extracts as chelating agents. This contains pomeloextract. This study presents the initial evidence of environmentally friendly hydroxyapatite nanoparticle synthesis using pomelo extract. The nanoparticles underwent an evaluation to determine their purity, size and shape. The efficacy of the nanostructures in combating malignancies was assessed using MCF-7 and MG-66 cancer cell lines.

Materials and Methods

Preparation of Extract

Before starting, thoroughly wash the pomelo fruit with clean water to remove any dirt or debris. The pomelo peel was carefully removed using a vegetable peeler. Next, remove the white, pithy membranes from the pomelo flesh by hand. Use an electric juicer to extract the juice from the pomelo segments. Finally, filter the juice through a fine-pore alloy mesh to remove any solids and ensure a clear, smooth juice for further experiments.

Green synthesis of GHAP nanoparticles

The hydroxyapatite synthesis procedure included dissolving calcium chloride and phosphoric acid separately in double deionized water using continuous sonication. The concentrations of the precursor solutions were 1.0 M for calcium chloride and 0.6 M for phosphoric acid. A solution with a concentration of 20 mg per mL was prepared by diluting the pomelo fruit extract in distilled water. The solution was then exposed to sonication for a period of 20 minutes. 50 mL of calcium solution was slowly added to an equal quantity of pomelo fruit extract to promote the creation of the hydroxyapatite precursor, while simultaneously continuing the process of sonication. Subsequently, a gradual addition of 50 mL of the P ion solution was performed dropwise to the combination, while using continuous sonication. The green suspension underwent further sonication for a duration of 10 minutes and was thereafter left to age for 10 hours with moderate stirring. This stage is considered critical in the production process of hydroxyapatite. The suspension was transferred to a 50mL autoclave jar that was tightly sealed.

The whole assembly was exposed to microwave irradiation at a temperature of 100 °C for 30 minutes, with a power output of 300 W, leading to the elimination of the template. Subsequently, the autoclave was allowed to reach the ambient temperature. The contents were subjected to centrifugation at a speed of 5000 revolutions per minute for a period of 10 minutes. The green solid obtained was extensively washed by many rounds of dispersion, centrifugation and redispersion using distilled water and alcohol until it achieved a neutral condition. A control sample was prepared by doing a parallel synthesis using pure water instead of a fruit extract solution, while following the identical method. The precipitates were dried in an oven at a temperature of 100 °C overnight after being washed. Ultimately, they were pulverized into a fine powder using a pestle and mortar. The washed sediments are transferred to an oven and subjected to a temperature of 100°C for a period of 10 hours. A green powder was produced by the process of calcination, where it was exposed to a temperature of 900°C for a period of 5 hours. The hydroxyapatite sample synthesized in the presence of fruit extract is labelled as GHAP, while the hydroxyapatite sample without fruit extract is labelled as HAP.

Characterization

We used various techniques to analyse the GHAP nanoparticles. Fourier

transform infrared spectroscopy (FT-IR) with a Perkin Elmer spectrometer revealed the chemical composition. X-ray diffraction (XRD) using a Rigaku diffractometer identified the crystal structure of the GHAP material. Scanning electron microscopy (SEM) from TESCAN visualized the overall shape and texture of the nanoparticle powder. Additionally, energy dispersive spectroscopy (EDS) provided information on the elemental makeup. Finally, transmission electron microscopy (TEM) with a JEM-1011 instrument offered a high-resolution view of the individual nanoparticle morphology.

Cell Viability

The MTT dye reduction method was used to indirectly determine the percentage of alive cells by measuring the decrease in MTT caused by active mitochondria in living cells ^[16]. The experiment included placing 30,000 cells in each well of 96-well plates and allowing them to incubate for 2 hours at a temperature of 37°C with a CO₂ concentration of 5%. The cells were treated with MTT (1 mg/mL) in DMEM medium. Following incubation, the formazan crystals were dissolved in dimethyl sulfoxide (DMSO) after being washed with phosphate-buffered saline (PBS). Ultimately, the optical density (OD) at a wavelength of 570 nm was quantified using an ELISA reader, while cell pictures were acquired using an Olympus fluorescent microscope.

DAPI Staining

We conducted a DAPI staining assay to examine the attachment of MC3T3-E1 cells with nanoparticles. The cells were placed on plates at a density of 10,000 cells per well and exposed to the nanoparticles for either seven or twenty-one days. In order to evaluate cell adhesion, they conducted a sequence of procedures: rinsing the samples with a phosphate buffer solution (PBS), immobilizing the cells with a paraformaldehyde solution and rinsing once more with PBS. then, the researchers made the cell membranes permeable by using a gentle detergent (Triton X-100) and then rinsed them again with PBS. After three final washes with PBS, the samples were maintained in cold, dark conditions until being photographed using an Olympus fluorescent microscope ^[17].

Results and Discussion

FTIR Analysis of GHAP Nanoparticles

FTIR spectroscopy was used to identify the pomelo extract responsible for the creation and stabilization of green-synthesized hydroxyapatite particles (GHAP). Figure 2a displays the FTIR absorption patterns of GHAP.

GHAP exhibited distinct spectral bands in comparison to chemically synthesized hydroxyapatite (CHAP) (Fig. 2b). Both kinds of nanoparticles exhibited similar spectral features, with prominent bands seen at 649 cm^{-1} and 1631 cm^{-1} . In addition, both GHAP and CHAP displayed distinct and intense bands within certain frequency ranges: $567\text{--}620\text{ cm}^{-1}$, $900\text{--}1100\text{ cm}^{-1}$ and 2925 cm^{-1} [18]. The GHAP spectra exhibited distinct peaks at 463 and 874 cm^{-1} , as well as wide peaks at 1402 and 1460 cm^{-1} [19]. The FTIR examination, which is known for its great sensitivity, could not identify any specific bands associated with organic functional groups, suggests that the GHAP is pure.

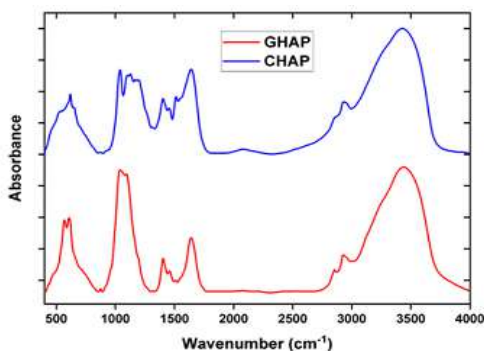


Fig. 1: FTIR spectrum of green synthesis hydroxyapatite (GHAP) and chemical synthesis of hydroxyapatite (CHAP)

Crystalline phase of GHAP nanoparticles

Figure 2 shows that the XRD examination indicates that the green-synthesized GHAP nanoparticles have sharper and more prominent peaks compared to the CHAP material. The bands seen in the GHAP structure correspond to certain crystal planes. These planes are labelled as follows: (002) 25° , (102) 28° (210) 28° , (211) 31° , (300) 32° , (202) 33° , (130) 39° , (131) 42° , (222) 46° , (213) 49° , (004) 53° and (304) 64° [20]. By cross-referencing the peaks with the JCPDS reference number 896439, we can verify the highly organized hexagonal lattice structure of the GHAP nanoparticles. The high acuity of the bands in the XRD profile indicates the excellent crystallinity of the end product. The discovery, in conjunction with the outcomes of TEM-SAED research, indicates that the GHAP nanoparticles possess a well-defined hexagonal nanocrystalline configuration.

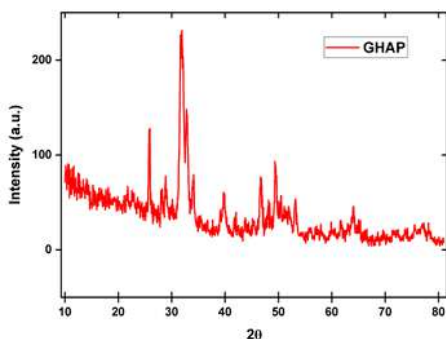


Fig. 2: XRD pattern of GHAP nanoparticles

Microstructure of GHAP nanoparticles

Figure 3a-b reveals the size and morphology of the GHAP nanoparticles developed in the presence of pomelo extract by using SEM technology. The image presents the sample as individual, quite homogeneous particles with a very consistent morphology. Measuring from 30 to 80 nm in size, these particles EDAX spectroscopy helped us determine the elemental composition of GHAP. Figures 3c&d show the EDAX spectra and elemental mapping images of the GHAP. With no appreciable evidence of additional compounds, these spectra reveal unambiguous peaks for calcium (Ca), phosphorous (P) and oxygen (O). This guarantees GHAP's purity and shows an about 1.65 calcium to phosphorous ratio ^[21]. Figure 3 shows high-resolution TEM pictures of the particles at two distinct magnification levels. The images show that the nanoparticles are mainly round and clustered together, with each particle varying in size from 40 to 60 nm.

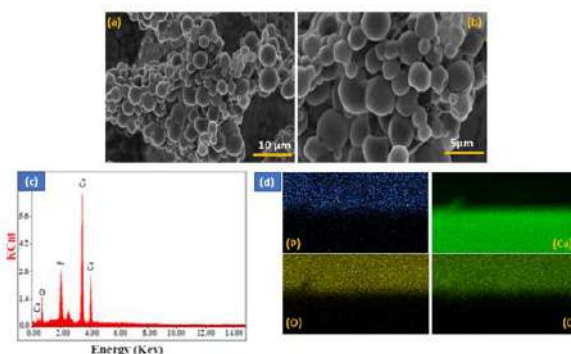


Fig. 3: (a-b) SEM images; (c) EDAX spectrum and (d) elemental mapping of GHAP nanoparticles

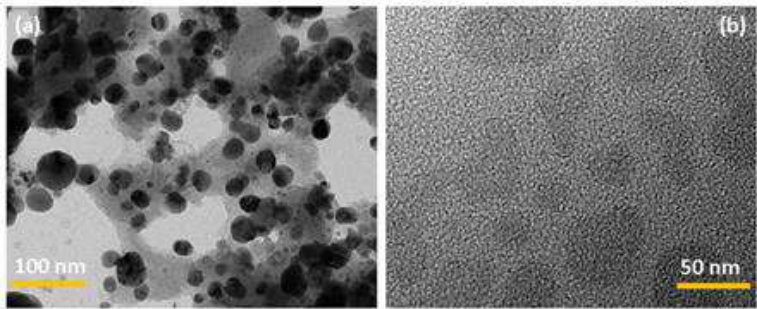


Fig. 4: (a-b) TEM images of GHAP nanoparticles.

Cell Viability Assay

Figure 5 specifically explores the biocompatibility of the synthesized GHAP nanoparticles with MC3T3-E1 cells, a well-established cell line representing osteoblasts (bone-forming cells). The results in Figure 5 likely show high cell viability (%) of MC3T3-E1 cells treated with different concentrations (25-100 mg/ml) of GHAP nanoparticles at 1 and 3-day intervals. This high cell viability suggests good biocompatibility, implying the GHAP nanoparticles do not harm or significantly hinder the growth and function of osteoblasts. This finding is crucial for bone tissue engineering applications. Biocompatible materials are essential for scaffolds and implants used to regenerate bone [22].

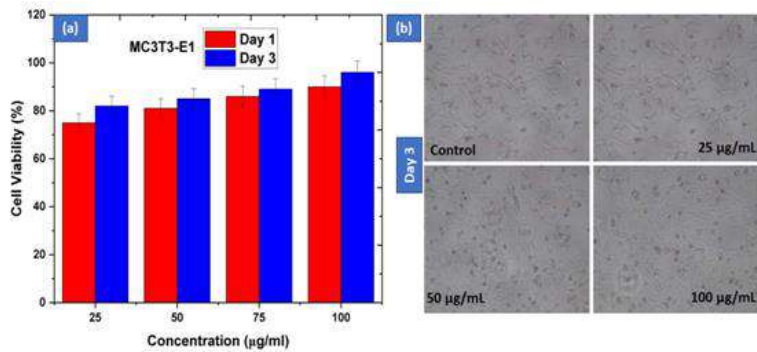


Fig. 5: Cell viability of MC3T3-E1 cells treated with GHAP nanoparticles at various concentrations (25-100 µg/mL) throughout incubation periods of 1 and 3 days(n=3).

Cell Adhesion

This study examined the adhesion and differentiation of MC3T3-E1 pre-osteoblast cells on GHAP nanoparticles using DAPI labelling. The cells were

cultured on the nanoparticles for a period of 1 and 3 days. DAPI labelling specifically attaches to the nuclei of cells, allowing us to see and quantify cell adhesion and differentiation. Untreated cells were used as the control group. Fluorescence microscopy images (Fig. 6) clearly show the specific binding of MC3T3-E1 cells to the GHAP nanoparticles after 1 and 3 days. The DAPI staining displays a vivid blue colour, demonstrating the existence of intact and healthy cell nuclei in cells coupled to GHAP nanoparticles ^[23].

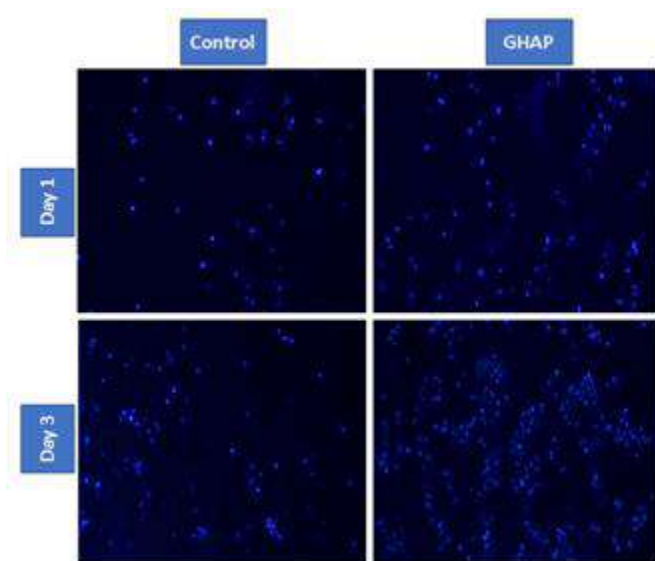


Fig. 6: Images of DAPI staining after the cultivation of MC3T3-E1 on GHAP nanoparticles for 1 and 3 days.

Anticancer Activity

The research examined the impact of GHAP that were manufactured using green methods on the proliferation of osteoblast cancer cells. We used an MTT test to quantify MCF-7 cell survival after exposure to GHAP at various doses for 1 and 3 days (Figure 7). The findings demonstrated a distinct and proportional impact of GHAP dosage on cell viability, with the presence of GHAP leading to a considerable decrease in cell viability. This indicates that GHAP has a potent cytotoxic impact on these MCF-7 cells. There are many potential reasons for this phenomenon. MCF-7 cells have a propensity for fast division and possess an elevated metabolic rate. They may also have a higher propensity to adopt GHAP in comparison to healthy cells. The heightened internalization of GHAP may result in an elevated rate

of cellular apoptosis. Curiously, while the degree of toxicity progressively rose over time for all concentrations, the total toxicity across various dosages became more comparable after a period of 3 days. This indicates that beyond a certain timeframe, all GHAP dosages that were examined may have a comparable impact on the viability of cells in this particular MCF-7 cell line.

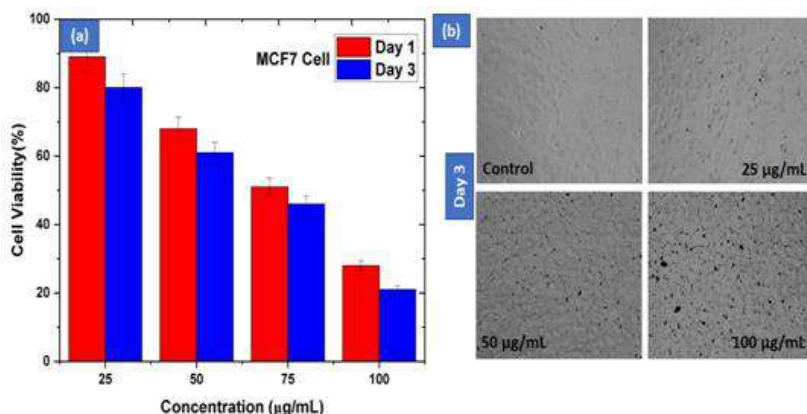


Fig 7: *In vitro* anticancer activity of MCF-7 cells treated with GHAP nanoparticles at various concentrations (25-100 µg/mL) throughout incubation periods of 1 and 3 days (n=3).

Figure 8 shows the results of a cell viability test on MG63 osteosarcoma cells treated with GHAP nanoparticles at different concentrations for 1 and 3 days. The reduced cell viability observed here is likely due to several factors. GHAP may cause the production of harmful molecules called reactive oxygen species within the cells. Additionally, it could lower the amount of ATP (a molecule cells use for energy) and decrease the activity of enzymes involved in energy production.

These effects disrupt the mitochondria (the cell's powerhouses) and other cellular components, ultimately leading to cell death. It's important to note that unlike some other nanoparticles that might simply damage cell membranes, GHAP's cytotoxicity seems to rely on specific mechanisms within the targeted cells. These mechanisms can vary depending on the cell type. These factors are the duration of exposure, the nanoparticle's morphology, size and surface chemistry. Interestingly, the study found that GHAP exhibited higher toxicity towards MCF-7 cells compared to MG63 cells. Finally, the duration of treatment also plays a role in GHAP's ability to inhibit cell proliferation.

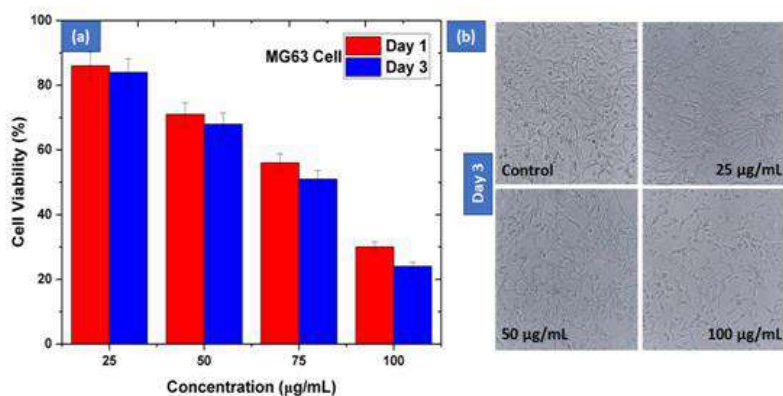


Fig. 8: *In vitro* anticancer activity of MG63 cells treated with GHAP nanoparticles at various concentrations (25-100 µg/mL) throughout incubation periods of 1 and 3 days (n=3).

Conclusion

This research successfully synthesized hydroxyapatite nanoparticles (GHAP) using a green and efficient microwave-assisted approach with pomelo extract. The resulting GHAP exhibited high purity, confirmed by FTIR and XRD analysis, indicating the absence of organic residues from the extract. FESEM and TEM analysis revealed nanosized with good homogeneity. Furthermore, GHAP demonstrated excellent biocompatibility as shown by the high cell viability of MC3T3-E1 cells in its presence. DAPI staining further confirmed the attachment and spreading of these healthy bone cells on GHAP nanoparticles. Interestingly, MTT assays revealed significant cytotoxic effects of GHAP against MCF-7 and MG63 cancer cells, with minimal impact on healthy bone cells (MC3T3-E1). This selective cytotoxicity highlights GHAP's potential as an anti-cancer agent, particularly for osteosarcoma and breast cancer. This research paves the way for the development of GHAP as a versatile biomaterial with significant potential in both bone regeneration and targeted cancer therapy.

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CHAPTER

Environmental Governance in India: A Study on Constitutional and International Perspective

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Abstract

Environmental governance has become one of the most significant concerns of contemporary public policy due to rapid industrialization, urbanization, population growth and ecological degradation. India, as a developing nation with immense ecological diversity and developmental aspirations, has established a comprehensive legal and institutional framework to address environmental challenges. This article examines the evolution of environmental governance in India through constitutional provisions, legislative developments and international commitments. It explores the role of major environmental statutes, including the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981, the Environment (Protection) Act, 1986 and other related enactments. The study further investigates India's participation in international environmental treaties such as the Stockholm Declaration, Rio Declaration, Convention on Biological Diversity and Paris Agreement. Employing a doctrinal research methodology, the article analyses legal provisions, policy frameworks and scholarly literature to assess the effectiveness of environmental governance mechanisms. The findings indicate that while India has developed a robust legal framework, challenges relating to implementation, institutional coordination and enforcement continue to hinder effective environmental protection. The article concludes by emphasizing the need for integrated governance, stronger regulatory institutions and greater

public participation to achieve sustainable development.

Keywords: Environmental governance, environmental legislation, constitutional law, sustainable development, international environmental law, environmental policy.

Background of the Study

Environmental degradation has emerged as one of the most pressing global challenges of the twenty-first century. Rapid industrialization, urban expansion, deforestation, biodiversity loss, climate change and pollution have intensified concerns regarding the sustainability of natural resources. For developing countries such as India, balancing economic growth with environmental conservation remains a complex challenge. India possesses a rich ecological heritage comprising forests, rivers, wetlands, coastal ecosystems and diverse wildlife. However, increasing population pressure and developmental activities have placed immense stress on these natural resources. Consequently, environmental governance has become an essential component of public administration and legal policymaking. Environmental governance refers to the processes, institutions, laws and policies through which environmental issues are managed and regulated (Environmental Governance, n.d.).

The foundation of environmental governance in India can be traced to international environmental movements and constitutional developments. The United Nations Conference on the Human Environment held in Stockholm in 1972 marked a turning point in global environmental consciousness. Following the conference, India adopted several legislative and constitutional measures to strengthen environmental protection (United Nations, 1992). The Forty-Second Constitutional Amendment Act of 1976 introduced Article 48A under the Directive Principles of State Policy, directing the State to protect and improve the environment. Simultaneously, Article 51A(g) imposed a fundamental duty upon citizens to protect and preserve the natural environment. These constitutional provisions provided the basis for subsequent legislative and judicial developments. Over the years, India has enacted numerous environmental laws aimed at pollution control, biodiversity conservation, forest protection and sustainable resource management. Moreover, India has actively participated in international environmental treaties and conventions, demonstrating its commitment to global environmental governance. Nevertheless, despite extensive legal frameworks, environmental degradation remains a persistent concern, necessitating a

critical examination of existing governance mechanisms.

Literature Review

Environmental governance in India has evolved through a combination of constitutional mandates, statutory frameworks, judicial interventions and international environmental commitments. Environmental governance is increasingly understood as a multidimensional process involving state institutions, civil society, market actors and local communities working collectively toward sustainable resource management and environmental protection (Lemos & Agrawal, 2006). Studies on Indian environmental governance have emphasized that effective governance extends beyond regulatory compliance and requires institutional accountability, public participation and decentralized decision-making (Jairaj et al., 2013). According to Chakraborty (2020), modern environmental governance in India reflects a transition from traditional command-and-control approaches toward more participatory and collaborative governance structures. The literature further identifies several persistent challenges, including weak enforcement mechanisms, fragmented institutional arrangements, inadequate monitoring systems and limited stakeholder participation despite the existence of comprehensive environmental legislation such as the Environment (Protection) Act, 1986, the Water (Prevention and Control of Pollution) Act, 1974 and the Air (Prevention and Control of Pollution) Act, 1981 (Jairaj et al., 2013). Scholars also note that judicial activism has played a crucial role in strengthening environmental governance through the expansion of environmental rights under Article 21 of the Constitution and the application of principles such as the precautionary principle, polluter-pays principle, public trust doctrine and intergenerational equity (Chakraborty, 2020). Furthermore, the outcomes of the Rio Earth Summit significantly influenced environmental policy worldwide by promoting sustainable development through Agenda 21 and encouraging countries, including India, to integrate environmental concerns into development planning (United Nations, 1992). More recent literature highlights the growing importance of climate governance, environmental justice, indigenous rights, technological innovations in environmental monitoring and adaptive governance frameworks capable of responding to emerging environmental challenges. Collectively, these studies conclude that while India has made considerable progress in aligning environmental governance with sustainable development objectives and international environmental commitments, substantial gaps remain in implementation, institutional coordination, environmental justice

and long-term ecological sustainability (Jairaj et al., 2013; Chakraborty, 2020).

Objectives of the Study

The study aims to achieve the following objectives:

1. To examine the constitutional foundations of environmental governance in India.
2. To analyse the development and scope of major environmental legislations in India.
3. To evaluate the influence of international environmental agreements on domestic environmental law.
4. To assess the effectiveness of India's environmental governance framework.
5. To identify challenges and suggest measures for strengthening environmental governance and sustainable development.

Methodology

The present study adopts a doctrinal and analytical research methodology. The research is based primarily on secondary sources of information, including constitutional provisions, statutes, judicial decisions, government reports, policy documents, scholarly articles, books and international legal instruments. Relevant environmental legislations such as the Environment (Protection) Act, 1986, the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981 and the Forest (Conservation) Act, 1980 have been examined. International environmental agreements including the Stockholm Declaration, Rio Declaration, Convention on Biological Diversity and Paris Agreement have also been analysed.

Result and Analysis

Constitutional Foundations of Environmental Governance

The Indian Constitution provides a strong foundation for environmental protection. The Forty-Second Constitutional Amendment Act of 1976 introduced environmental concerns into the constitutional framework through Articles 48A and 51A(g). Article 48A directs the State to protect and improve the environment and safeguard forests and wildlife, while Article 51A(g) imposes a duty upon every citizen to protect and improve the natural

environment, including forests, lakes, rivers and wildlife. These constitutional provisions have significantly influenced legislative and policy developments and have provided the judiciary with a constitutional basis for expanding environmental rights under Article 21, which guarantees the right to life and personal liberty. The Supreme Court held that the right to life includes the right to a wholesome and pollution-free environment in *Rural Litigation and Entitlement Kendra v. State of Uttar Pradesh* (1985) and further expanded environmental rights in *Subhash Kumar v. State of Bihar* (1991). Similarly, in *M.C. Mehta v. Union of India* (1987), the Court recognized environmental protection as an essential component of the constitutional right to life.

Evolution of Environmental Legislation

Environmental legislation in India has evolved substantially since the 1970s. The Stockholm Conference acted as a catalyst for legislative reforms. One of the earliest major environmental statutes was the Water (Prevention and Control of Pollution) Act, 1974, enacted to prevent and control water pollution. Subsequently, the Air (Prevention and Control of Pollution) Act, 1981 was introduced to regulate industrial emissions and improve air quality standards. Following the Bhopal Gas Tragedy of 1984, the Environment (Protection) Act, 1986 was enacted as umbrella legislation providing comprehensive powers to the Central Government for environmental protection (Jairaj et al., 2013). Judicial intervention played a significant role in strengthening environmental legislation. In *Indian Council for Enviro-Legal Action v. Union of India* (1996), the Supreme Court reinforced the polluter-pays principle, while *Vellore Citizens Welfare Forum v. Union of India* (1996) formally incorporated both the precautionary principle and sustainable development into Indian environmental jurisprudence. Other important legislations include the Wildlife (Protection) Act, 1972, the Forest (Conservation) Act, 1980, the Biological Diversity Act, 2002 and various waste management rules governing hazardous waste, plastic waste and electronic waste. These laws collectively establish a broad regulatory framework for environmental management and conservation. The application of the public trust doctrine was further strengthened in *M.C. Mehta v. Kamal Nath* (1997), where the Court held that natural resources are held by the State in trust for public use and cannot be transferred for private exploitation.

International Perspectives

India's environmental governance framework has been significantly shaped by international environmental agreements. The Stockholm Declaration of 1972 laid the foundation for global environmental cooperation and inspired legislative reforms in India (United Nations, 1992). The Rio Earth Summit of 1992 further strengthened global environmental governance through Agenda 21 and the Rio Declaration. The summit emphasized sustainable development, environmental impact assessment and public participation. The Supreme Court has repeatedly relied on international environmental principles in domestic adjudication, particularly in *Vellore Citizens Welfare Forum v. Union of India* (1996) and *A.P. Pollution Control Board v. M.V. Nayudu* (1999), where the Court emphasized the precautionary principle and the need for scientific expertise in environmental decision-making.

India is also a party to the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the Paris Agreement. These agreements have influenced domestic environmental policies concerning climate change mitigation, biodiversity conservation and sustainable resource management. The importance of balancing environmental protection with indigenous and community rights was highlighted in *Orissa Mining Corporation v. Ministry of Environment and Forests* (2013), commonly known as the Niyamgiri case, where the Supreme Court recognized the rights of tribal communities in environmental decision-making.

Institutional Framework

The Ministry of Environment, Forest and Climate Change (MoEFCC) serves as the principal governmental agency responsible for environmental policymaking and implementation. The Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) are responsible for monitoring pollution and enforcing environmental standards. Additionally, environmental impact assessment procedures and various regulatory authorities contribute to environmental decision-making processes. The judiciary has consistently emphasized the need for specialized environmental institutions. In *A.P. Pollution Control Board v. M.V. Nayudu* (1999), the Supreme Court recommended the establishment of environmental courts with technical expertise. This recommendation ultimately contributed to the creation of the National Green Tribunal (NGT) under the National Green

Tribunal Act, 2010, which serves as a specialized forum for environmental adjudication. The NGT has subsequently played a critical role in enforcing environmental standards, addressing pollution and promoting sustainable development across India.

Challenges in Environmental Governance

First, implementation and enforcement remain weak despite the existence of comprehensive legislation. Regulatory agencies often face shortages of technical expertise, financial resources and monitoring infrastructure.

Second, overlapping jurisdictions among governmental agencies create administrative complexities and reduce policy effectiveness.

Third, rapid industrialization and urbanization continue to generate environmental pressures that exceed existing regulatory capacities.

Fourth, public participation in environmental decision-making remains limited despite legal provisions promoting stakeholder engagement.

Finally, climate change presents new challenges requiring adaptive governance frameworks capable of addressing emerging environmental risks.

Conclusion and Recommendations

Environmental governance in India has undergone remarkable transformation over the past five decades. Constitutional provisions, legislative initiatives and international commitments have collectively contributed to the development of a comprehensive environmental protection framework. The enactment of major environmental laws and the incorporation of global environmental principles into domestic policymaking reflect India's commitment to sustainable development.

However, the effectiveness of environmental governance depends not merely on the existence of legal provisions but on their implementation and enforcement. Institutional weaknesses, resource constraints, inadequate coordination and emerging environmental challenges continue to hinder environmental protection efforts. To address these concerns, India must strengthen regulatory institutions, promote public participation, improve inter-agency coordination and integrate environmental sustainability into all aspects of governance. Achieving sustainable development requires a holistic approach that balances economic growth with environmental conservation and social well-being. Such an approach will ensure the protection of natural resources for present and future generations while fulfilling national and

international environmental obligations.

The study suggests that environmental governance must move beyond traditional command-and-control approaches and embrace integrated, participatory and adaptive strategies. Strengthening institutional capacities, enhancing transparency, promoting environmental education, encouraging stakeholder participation and integrating scientific research into policymaking can significantly improve governance outcomes. Moreover, environmental considerations should be incorporated into economic planning to ensure that development objectives remain consistent with sustainability principles.

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CHAPTER

Green Justice and Governance: Judicial Activism in Shaping India's Environmental Future

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Abstract

Environmental governance in India has undergone significant transformation since the 1970s, driven by constitutional mandates, legislative developments, judicial interventions and international environmental commitments. The Indian legal framework has evolved to address complex environmental challenges through statutes such as the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981 and the Environment (Protection) Act, 1986. Simultaneously, the judiciary has expanded environmental rights under Article 21 of the Constitution and developed principles such as sustainable development, the precautionary principle, the polluter-pays principle and the public trust doctrine. Despite these advancements, environmental governance continues to face challenges including weak enforcement, institutional fragmentation, inadequate monitoring mechanisms and conflicts between development and conservation objectives. This study examines the evolution, scope and limitations of environmental governance and legislation in India through an analysis of constitutional provisions, statutory frameworks, judicial precedents and international environmental obligations. The findings reveal that while India possesses a comprehensive environmental regulatory framework, significant implementation gaps hinder its effectiveness. The study concludes by recommending stronger institutional coordination, enhanced public participation and adaptive governance mechanisms to address emerging environmental challenges.

Keywords: Environmental Governance, Sustainable Development, Judicial

Activism, Restorative Justice, National Green Tribunal,

Background of the Study

Environmental degradation has emerged as one of the most pressing challenges confronting modern societies. Rapid industrialization, urbanization, deforestation, biodiversity loss and climate change have intensified environmental concerns globally. In India, environmental governance has evolved as a response to these challenges through a combination of constitutional provisions, legislative enactments, judicial interventions and international commitments. The Stockholm Conference of 1972 marked a turning point in global environmental governance and significantly influenced India's environmental policy framework (United Nations, 1992). Subsequently, the Forty-Second Constitutional Amendment Act, 1976 introduced Articles 48A and 51A(g), establishing environmental protection as both a state responsibility and a fundamental duty of citizens. These provisions provided the foundation for the development of environmental legislation and judicial activism in India. Over the years, environmental governance has expanded beyond pollution control to encompass sustainable development, biodiversity conservation, climate governance, environmental justice and indigenous rights (Lemos & Agrawal, 2006). Nevertheless, the effectiveness of environmental governance remains contested due to implementation challenges, regulatory inefficiencies and competing developmental priorities.

Literature Review

Environmental governance is broadly understood as the set of regulatory processes, institutions and mechanisms through which environmental issues are managed and resolved (Lemos & Agrawal, 2006). According to Lemos and Agrawal (2006), environmental governance involves interactions among governments, civil society organizations, private actors and local communities in achieving environmental sustainability.

Jairaj et al. (2013) examined environmental governance initiatives in India and observed that despite the existence of comprehensive legal frameworks, implementation remains constrained by weak institutional capacity, inadequate monitoring and poor coordination among regulatory agencies. Their study highlighted the need for stronger enforcement mechanisms and stakeholder participation.

Chakraborty (2020) argued that modern environmental governance in India has shifted from traditional state-centric approaches toward participatory and collaborative governance frameworks. The study emphasized the

increasing role of judicial institutions, non-governmental organizations and local communities in environmental decision-making.

The Rio Earth Summit of 1992 further strengthened the concept of sustainable development and promoted environmental impact assessments, public participation and integrated resource management (United Nations, 1992). Subsequent scholarship has recognized environmental governance as a multidimensional framework that incorporates environmental protection, social equity and economic development.

Recent literature also emphasizes environmental justice and indigenous rights, highlighting the need to balance conservation goals with the socio-economic rights of forest-dependent and tribal communities. Scholars have increasingly acknowledged that environmental governance must address both ecological sustainability and social inclusion (Chakraborty, 2020).

Objectives of the Study

The study aims:

1. To examine the evolution of environmental governance and legislation in India.
2. To analyze the constitutional and legal foundations of environmental protection.
3. To evaluate the role of judicial interventions in strengthening environmental governance.
4. To identify the limitations and challenges of environmental legislation in India.
5. To suggest measures for improving environmental governance and regulatory effectiveness.

Methodology

The study adopts a doctrinal and qualitative research methodology. Data have been collected from secondary sources including books, journal articles, government reports, judicial decisions, international environmental declarations and statutory instruments. The research primarily relies on content analysis of legal texts, judicial precedents and scholarly literature relating to environmental governance and legislation in India.

Results and Analysis

The analysis reveals that environmental governance in India is supported by a robust constitutional and legislative framework. Articles 48A and 51A(g)

provide constitutional recognition to environmental protection, while Article 21 has been judicially interpreted to include the right to a clean and healthy environment (*Subhash Kumar v. State of Bihar*, 1991).

Judicial activism has significantly expanded environmental jurisprudence. In *Rural Litigation and Entitlement Kendra v. State of Uttar Pradesh* (1985), the Supreme Court recognized environmental protection as an integral aspect of the right to life. Similarly, *M.C. Mehta v. Union of India* (1987) established strict liability principles for hazardous industries and strengthened environmental accountability.

The Supreme Court further institutionalized sustainable development through *Vellore Citizens Welfare Forum v. Union of India* (1996), where the precautionary principle and polluter-pays principle were formally incorporated into Indian environmental law. In *Indian Council for Environmental Action v. Union of India* (1996), industries causing environmental damage were held financially responsible for remediation.

The public trust doctrine was recognized in *M.C. Mehta v. Kamal Nath* (1997), wherein the Court held that natural resources are held in trust by the State for public use. Likewise, *A.P. Pollution Control Board v. M.V. Nayudu* (1999) emphasized the importance of scientific expertise in environmental adjudication and recommended specialized environmental courts.

Despite these developments, several limitations persist. Regulatory agencies often suffer from inadequate technical expertise, insufficient funding and overlapping jurisdictions. Environmental Impact Assessment procedures are frequently criticized for procedural deficiencies and inadequate public consultation. Furthermore, conflicts between economic development and environmental conservation continue to challenge policy implementation. The establishment of the National Green Tribunal (NGT) in 2010 represents a significant institutional innovation aimed at improving environmental adjudication. However, case backlogs, resource constraints and enforcement challenges continue to affect its effectiveness.

Indian Judiciary has evolved few principles for environment governance:

i) Right to a Healthy Environment

The Stockholm Declaration of 1972, adopted by the United Nations, acknowledged the importance of both natural and human-made aspects of the environment. It also affirmed that protecting the environment is crucial for human well-being and the enjoyment of basic human rights, including the right to life itself. In India, the Supreme Court has strengthened and broadened

the fundamental right enshrined in Part III of the Constitution. Through this process, the scope of the fundamental right to life and personal liberty guaranteed in Article 21 of the Indian Constitution has been expanded to encompass environmental protection.

ii) Doctrine of Locus Standi

The traditional concept of locus standi, which is applicable in conventional private law litigation, has been liberalized by Indian courts in cases of Private Interest Litigation. Traditionally, standing was based on the notion of the aggrieved person. However, courts have embraced a new approach by permitting any member of the public to seek legal redress for harm caused to an individual or a specific class of persons who, due to poverty, helplessness, disability, or social disadvantage, are unable to directly approach the court. This modification of the traditional locus standi can be termed as "representative standing," as it allows representation of another person or group. This concept refutes the traditional assumption that only self-interest motivates petitioners. The Supreme Court and High Courts of India have exercised jurisdiction and issued orders to prevent ecological harm. This has been achieved through superior courts entertaining writ petitions via public interest litigation, which serves as a class action aimed at protecting ecology, preventing pollution and benefiting victims by awarding damages in appropriate cases. The orthodox rule requiring petitioners to have personal interest in order to file a writ petition has been eliminated. Individual environmentalists, non-governmental organizations and others have filed writ petitions related to various types of polluting industries, as well as for the enforcement and implementation of environmental laws.

iii) Doctrine of Parens Patriae

The Bhopal gas leak disaster, the enactment of the Bhopal Gas Disaster (Processing of Claims) Act of 1985, the unsuccessful attempt by the Union Government to litigate the case in an American court and the subsequent settlement agreement between the Union Carbide Corporation and the Union Government are well-known events. Therefore, it suffices to say that the Supreme Court applied the doctrine of parens patriae to validate the Bhopal Gas Disaster (Processing of Claims) Act of 1985, which transferred the rights of individual victims to claim compensation independently and vested them in the Union Government.

The concept of parens patriae, meaning "parent of the country," traditionally refers to the role of the state as a sovereign and guardian of individuals under legal disability. It is recognized both in India and abroad,

with its roots in the common law concept of the royal prerogative. The royal prerogative included the right or responsibility to care for persons who were legally incapable of caring for themselves.

iv) Doctrine of Public Trust

The ancient Roman Empire established a legal doctrine known as the "Doctrine of the Public Trust," which was based on the belief that the government held certain common resources such as rivers, seashores, forests and air in trust for the unrestricted use of the general public. This doctrine is primarily rooted in the principle that certain resources, such as air, sea, water and forests, are of such vital importance to society as a whole that it would be unjustifiable to subject them to private ownership. As these resources are gifts of nature, they should be accessible to everyone regardless of their social status. The doctrine mandates that the government protect these resources for the enjoyment of the general public rather than allowing their use for private or commercial purposes. Courts have applied the public trust doctrine in the management of natural resources and the environment, often considering concepts of intergenerational and intragenerational equity. For instance, in the Rural Litigation and Entitlement Kendra v. State of U.P. case the Court ordered the cessation of unauthorized and illegal mining in the Dhera Dun District, noting that the area was a natural gift to humanity and a legacy from past generations to future ones.

v) Intergenerational Equity

Intergenerational equity refers to the right of each generation to benefit from the cultural and natural heritage passed down by past generations, as well as the responsibility to preserve such heritage for future generations. In the Ganesh Wood Products case, the Supreme Court recognized the obligation of the present generation to conserve natural resources for future ones. The Court emphasized that the present generation cannot compromise the safety and well-being of future generations. Similarly, in the Coastal Regulation Zone (CRZ) Notification Case, the Court observed that environmental statutes were enacted to ensure a good quality of life for future generations, as they would bear the consequences of ecological degradation.

vi) Public Liability

The judiciary has emphasized the responsibility and liability of industries through its support of the "polluter pays" principle. This principle was specifically addressed in the 1996 Supreme Court decision of Indian Council for Enviro-Legal Action v. Union of India, where the Court held industries strictly liable for harm caused by hazardous activities. The Court endorsed the

principle that those who cause pollution should bear the financial costs of preventing or remedying damage, as exemplified in the Vellore Citizens Welfare Forum v. Union of India case.

vii) Right to Information

The public's right to information has been underscored in India, as seen in the Bombay Environment Action Group, Shyam H.K. Chainani Indian Inhabitant, Save Pune Citizen's Committee v. Pune Cantonment Board case. The Court upheld the right to information and the rights of recognized social action groups to access such information, stating that it stems from the constitutional right to free speech and expression. The Court emphasized the importance of public participation in environmental protection and mandated the government to educate citizens about environmental issues, as evidenced in the M.C. Mehta v. Union of India case.

viii) Precautionary Principle

The precautionary principle is utilized in international environmental law when faced with scientific uncertainty. This approach began to emerge in international legal agreements around the mid-1980s. It gained formal acknowledgment in Principle 15 of the Rio Declaration, stating that in cases of serious or irreversible threats of damage, lacking full scientific certainty should not hinder preventive measures. Starting with the case of Vellore Citizens' Welfare Forum v. Union of India, the Supreme Court of India has explicitly acknowledged the precautionary principle as a fundamental aspect of Indian environmental law. More recently, in the case of A.P. Pollution Control Board v. M.V. Nayudu, the Court delved into the evolution of this principle.

ix) Polluter Pays Principle

The polluter-pays principle mandates that those responsible for causing pollution and its subsequent costs should bear the financial burden associated with it. This principle, rooted in treaty law, can be traced back to some of the earliest agreements establishing basic regulations on civil liability for damages arising from hazardous activities. Principle 16 of the 1992 Rio Declaration emphasizes the importance of internalizing environmental costs and utilizing economic mechanisms, while underscoring that polluters should generally bear the expenses of pollution, with consideration for the public interest and without adversely affecting international trade and environmental concerns. The Supreme Court has consistently upheld a stance where it determines environmental damages not based on claims from either party, but rather through its own assessment, taking into account factors such as the deterrent

effect of the award.

x) Indian Perspective on Indigenous Rights and Constitutionalism:

In the 36th LAWASIA Conference 2023, the fine line between indigenous rights and environmental protection has been made. Senior Advocate Harin P. Raval offered an insightful viewpoint from India, focusing on constitutional principles and the acknowledgment of indigenous rights. He emphasized the historical context leading to the formulation of the 1994 Declaration on Indigenous Rights and the subsequent adoption of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) in 2007. Raval stressed the inclusive nature of the declaration, centering on the survival, dignity and welfare of indigenous communities.

Senior Advocate Aditya Sondhi provided a detailed analysis of the treatment of indigenous peoples in India, revealing a troubling disparity between constitutional ideals and reality. Despite India's strong constitutional framework, Sondhi acknowledged that the experiences of indigenous peoples often involve appropriation and marginalization. Sondhi supported his argument by citing specific judicial rulings that, at times, reinforced stereotypes and misunderstandings about indigenous communities. He notably mentioned the *Chebrolu v State of Andhra Pradesh* case, where language such as "primitive" was used by a five-judge Constitution Bench to describe certain communities.

Additionally, Sondhi discussed colonial-era laws that negatively impacted indigenous communities, such as the Criminal Tribes Act, which unjustly labeled certain tribes as criminal based solely on socio-cultural practices. He suggested that subsequent laws, like the Habitual Offenders Act, continued to perpetuate prejudices against these tribes.

The conversation extended to contemporary issues, including the Forest Dwellers Act, which Sondhi argued undermines the rights of original dwellers by prioritizing environmental concerns over their historical coexistence with nature. He stressed the importance of recognizing the unique relationship indigenous peoples have with nature, criticizing narratives that tend to patronize and exclude them from mainstream discourse. Sondhi explored the concept of reimagining the Indian Constitution from an Adivasi perspective, lamenting the lack of representation, including the absence of a Scheduled Tribe judge in the Supreme Court of India. He also criticized societal perceptions, where issues concerning indigenous peoples often become fodder for entertainment rather than serious discussions about justice and rights.

Conclusions and Suggestions

The study concludes that India has developed an extensive framework of environmental governance through constitutional provisions, legislation, judicial innovations and international commitments. Environmental jurisprudence has evolved substantially, incorporating globally recognized principles such as sustainable development, the precautionary principle, the polluter-pays principle and intergenerational equity.

However, the effectiveness of environmental governance remains constrained by weak implementation, institutional fragmentation and inadequate enforcement mechanisms. Environmental protection requires not only strong laws but also effective institutions capable of ensuring compliance and accountability.

To strengthen environmental governance, regulatory agencies should be provided with greater financial and technical resources. Environmental monitoring systems should be modernized through the adoption of digital technologies and real-time compliance mechanisms. Public participation must be enhanced through transparent decision-making processes and improved access to environmental information. Greater coordination among governmental agencies, local bodies and civil society organizations is also necessary. Finally, environmental laws should be periodically reviewed and updated to address emerging challenges such as climate change, biodiversity loss and environmental justice concerns.

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17 CHAPTER

Beyond Legislative Silence: Judicial Activism and the Development of Environmental Governance in India

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Abstract

Environmental governance in India has evolved through a dynamic interaction between legislative frameworks, administrative institutions and judicial interventions. While India has enacted several environmental statutes to address pollution control, forest conservation and wildlife protection, persistent challenges such as weak enforcement, inadequate monitoring, insufficient funding and fragmented regulatory mechanisms have limited their effectiveness. In response to these shortcomings, the Indian judiciary has assumed an increasingly proactive role in environmental protection. Through judicial activism, courts have expanded environmental rights, developed innovative legal principles and strengthened environmental governance. This paper examines the limitations of environmental legislation in India, analyzes key judicial interventions, evaluates the role of the National Green Tribunal (NGT) and explores the future of environmental governance through the lens of judicial activism.

Keywords: Governance, Activism, Sustainability, Adjudication, Environment, Regulation, Conservation.

Introduction

Environmental governance refers to the processes, institutions, laws and policies through which environmental resources are managed and protected. In India, environmental governance has gained prominence due to rapid industrialization, urbanization, resource depletion and increasing environmental degradation (SAGE Publications, n.d.). Although India

possesses an extensive legal framework for environmental protection, implementation deficits have hindered the realization of environmental objectives. The judiciary has emerged as a critical actor in addressing these deficiencies. Through expansive interpretations of constitutional provisions and public interest litigation (PIL), courts have transformed environmental governance by integrating principles such as sustainable development, the precautionary principle and the polluter-pays principle into Indian environmental jurisprudence (*Vellore Citizens' Welfare Forum v. Union of India*, 1996).

Limitations of Environmental Legislation in India

Despite the existence of landmark statutes such as the Environment (Protection) Act, 1986, the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981 and the Forest (Conservation) Act, 1980, environmental governance in India continues to face significant challenges.

- **Inflexible Legislative Framework**

Environmental legislation in India largely follows a command-and-control model that emphasizes regulatory standards and penalties. While such an approach establishes environmental benchmarks, it often lacks flexibility and fails to accommodate technological advancements and sector-specific realities. As a result, industries may struggle to comply with unrealistic standards, reducing the effectiveness of environmental regulation.

- **Weak Enforcement Mechanisms**

One of the major weaknesses of environmental governance is ineffective enforcement. Regulatory authorities frequently lack the institutional capacity necessary to monitor compliance and implement environmental norms. Judicial observations in cases such as *M.C. Mehta v. Union of India* highlighted the failure of authorities to prevent environmental degradation despite existing legal provisions (*M.C. Mehta v. Union of India*, 1987).

- **Inadequate Monitoring and Technical Expertise**

State Pollution Control Boards often suffer from shortages of qualified technical personnel and modern monitoring infrastructure. Effective environmental management requires scientific expertise, yet many regulatory institutions remain dominated by administrative rather than technical personnel.

- **Insufficient Punitive Measures**

Environmental penalties often fail to reflect the magnitude of

environmental harm caused by polluters. Delays in judicial proceedings further undermine deterrence. The persistence of environmental violations despite legal sanctions demonstrates the need for stronger enforcement and accountability mechanisms.

- **Funding Constraints**

Environmental governance institutions frequently operate with inadequate financial resources. Limited funding restricts the ability of regulatory agencies to establish laboratories, conduct inspections and maintain monitoring systems, thereby weakening environmental protection efforts.

Judicial Activism and Environmental Governance

The shortcomings of legislative and administrative mechanisms have contributed to the rise of judicial activism in environmental governance. Indian courts have increasingly interpreted constitutional rights to include environmental protection and ecological sustainability.

Expansion of the Right to Life

The Supreme Court has interpreted Article 21 of the Constitution to include the right to a clean and healthy environment. This interpretation transformed environmental protection from a policy objective into a fundamental right enforceable through constitutional remedies (*Olga Tellis v. Bombay Municipal Corporation*, 1985).

Development of Environmental Principles

Judicial decisions have incorporated internationally recognized environmental principles into Indian law. In *Vellore Citizens' Welfare Forum v. Union of India* (1996), the Supreme Court formally adopted the precautionary principle and the polluter-pays principle, establishing them as essential components of Indian environmental jurisprudence.

Similarly, in *Indian Council for Enviro-Legal Action v. Union of India* (1996), the Court emphasized the responsibility of polluting industries to compensate affected communities and restore damaged ecosystems.

Specialized Environmental Adjudication

In *A.P. Pollution Control Board v. M.V. Nayudu* (1999), the Supreme Court recognized the technical complexity of environmental disputes and advocated for specialized environmental courts with scientific expertise. This judicial recommendation ultimately contributed to the establishment of the National Green Tribunal.

Protection of Natural Resources

Judicial activism has played a crucial role in safeguarding forests, rivers and biodiversity. In *State of Himachal Pradesh v. Ganesh Wood Products* (1996), the Supreme Court prioritized environmental conservation over commercial exploitation, emphasizing the importance of sustainable resource management.

National Green Tribunal and Environmental Governance

The establishment of the National Green Tribunal (NGT) under the National Green Tribunal Act, 2010 marked a significant development in environmental governance. The NGT was designed as a specialized forum for the speedy resolution of environmental disputes. The Tribunal possesses jurisdiction over matters relating to pollution control, environmental protection, forest conservation and natural resource management. Through its decisions, the NGT has strengthened environmental accountability and improved access to environmental justice. Notable NGT interventions include actions against industrial pollution, directives for river conservation, restrictions on environmentally harmful activities and enforcement of waste-management regulations. These decisions demonstrate the Tribunal's commitment to balancing environmental protection with developmental objectives.

However, challenges such as case backlogs, resource constraints and implementation difficulties continue to affect its effectiveness. Strengthening institutional capacity and improving coordination with regulatory agencies remain essential for enhancing the Tribunal's impact.

Evolution of Environmental Jurisprudence

The judiciary has played a transformative role in strengthening environmental governance in India, particularly in response to the inadequacies of legislative and administrative mechanisms. In *A.P. Pollution Control Board v. M.V. Nayudu* (1999), the Supreme Court emphasized the necessity of establishing specialized environmental courts with scientific and technical expertise. The Court observed that environmental disputes often involve complex scientific questions that require judges to be assisted by experts from relevant fields. This recommendation emerged from a comparative analysis of environmental adjudication systems adopted in several countries (*A.P. Pollution Control Board v. M.V. Nayudu*, 1999).

Similarly, in *M.C. Mehta v. Union of India* (1987), the Supreme Court advocated the establishment of regional environmental courts consisting of a

professional judge and technical experts. The Court recognized that environmental disputes require specialized knowledge and that conventional judicial institutions may lack the expertise necessary to address such matters effectively (*M.C. Mehta v. Union of India*, 1987).

The Supreme Court further reinforced this position in *Indian Council for Enviro-Legal Action v. Union of India* (1996), where it highlighted the urgent need for environmental courts possessing both civil and criminal jurisdiction to ensure the speedy resolution of environmental disputes and effective enforcement of environmental laws (*Indian Council for Enviro-Legal Action v. Union of India*, 1996).

In the *Kanpur Tanneries or Ganga Pollution* case, the Court examined the responsibilities of municipal authorities and pollution control boards in controlling water pollution. The Court noted the alarming deterioration of water quality in the Ganga River due to untreated sewage and industrial effluents discharged from Kanpur. It criticized municipal authorities for failing to perform their statutory duties and stressed the importance of effective environmental governance mechanisms (*M.C. Mehta v. Union of India*, 1988).

In *Attakoya Thangal v. Union of India* (1990), the petitioners challenged excessive groundwater extraction that had resulted in depletion of freshwater resources and salinity intrusion from the Arabian Sea. The Court emphasized that access to clean drinking water and a healthy environment forms an integral component of the fundamental right to life under Article 21 of the Constitution of India. The judgment underscored the state's obligation to protect natural resources for present and future generations (*Attakoya Thangal v. Union of India*, 1990).

Likewise, in *M.C. Mehta v. State of Orissa* (2023), the Court addressed the severe water pollution crisis in Cuttack arising from inadequate sewage treatment infrastructure and administrative negligence. The Court observed that the failure of state authorities to establish effective waste-treatment facilities had created serious public health concerns. Consequently, it directed the government to undertake immediate measures to prevent and control water pollution in accordance with constitutional and statutory obligations (*M.C. Mehta v. State of Orissa*, 2023).

National Green Tribunal and Environmental Governance

The establishment of the National Green Tribunal (NGT) under the National Green Tribunal Act, 2010 marked a significant milestone in India's environmental governance framework. The NGT functions as a specialized judicial body responsible for adjudicating environmental disputes and

ensuring the effective implementation of environmental laws. Its jurisdiction extends to matters concerning environmental protection, forest conservation, pollution control, biodiversity conservation and natural resource management (National Green Tribunal Act, 2010).

Since its inception, the NGT has played a pivotal role in enforcing environmental accountability and providing accessible environmental justice. Through its judgments and directives, the Tribunal has addressed numerous environmental concerns involving industrial pollution, waste management, deforestation and ecological degradation.

Despite its achievements, the NGT faces several institutional challenges, including case backlogs, delays in adjudication, limited infrastructure and the need for stronger coordination with environmental regulatory agencies. Scholars and policymakers have therefore advocated strengthening the Tribunal's institutional capacity and expanding its jurisdiction to address emerging environmental concerns such as climate change and ecological resilience (SAGE Publications, n.d.).

Several landmark decisions demonstrate the NGT's contribution to environmental governance. In *Vedanta Aluminium Ltd. v. Union of India*, the Tribunal ordered the closure of an alumina refinery in Odisha for violating environmental regulations, reaffirming the importance of strict compliance with environmental standards. Similarly, in *Subhash Chandra v. Union of India*, the NGT prohibited plastic bags thinner than 50 microns in Delhi to address the growing threat of plastic pollution.

In *M.C. Mehta v. Union of India* (2015), the Tribunal directed the Delhi government to implement immediate measures for controlling air pollution, including restrictions on vehicular emissions and industrial activities. The judgment significantly contributed to public awareness and policy responses concerning air quality management.

The NGT also played a crucial role in the Niyamgiri mining dispute by upholding the rejection of mining activities in ecologically sensitive tribal areas, thereby reinforcing the principles of environmental justice and indigenous rights. Likewise, in the Ganga Pollution Case (2017), the Tribunal issued comprehensive directions aimed at controlling industrial effluents, sewage discharge and solid waste disposal in the Ganga River basin.

In *Alembic Pharmaceuticals Ltd. v. Rohit Prajapati and Others* (2018), the Tribunal imposed environmental compensation on the company for groundwater contamination, reaffirming the application of the polluter-pays principle and emphasizing corporate accountability for environmental harm.

Conclusion and Suggestions

Environmental governance in India has evolved significantly through judicial intervention. Legislative deficiencies, weak enforcement and administrative challenges have compelled courts to play an active role in protecting environmental rights and promoting sustainable development. Through landmark decisions, the judiciary has transformed environmental protection into a constitutional imperative and established foundational principles of environmental law. While judicial activism has been instrumental in advancing environmental governance, long-term environmental sustainability requires comprehensive legislative reform, effective regulatory institutions, public participation and administrative accountability. The future of environmental governance in India depends upon achieving a balance between judicial oversight, legislative responsibility and sustainable development objectives.

Environmental governance in India can be strengthened through several reforms:

- Enhancing the institutional capacity of environmental regulatory authorities.
- Increasing penalties and accountability mechanisms for environmental violations.
- Improving coordination among governmental agencies involved in environmental management.
- Expanding environmental education and public participation.
- Periodically reviewing environmental legislation to address emerging challenges such as climate change.
- Promoting sustainable industrial practices and green technologies.
- Strengthening the National Green Tribunal through additional resources and technical expertise.
- Aligning domestic environmental policies with international environmental commitments.

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18

CHAPTER

Unseen Exposure, Unheard Needs: STI Vulnerability and Health Awareness among Sex Workers in West Bengal under SDG 3

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Abstract

Although HIV intervention programmes have been implemented in the country, a significant number of sex workers are still vulnerable to infection because of poor and inconsistent condom usage, stigma, financial limitations and lack of confidential and quality healthcare services. In the context of the United Nations Sustainable Development Goal 3 (Good Health and Well-being), the paper investigates the risk of sexually transmitted infections (STIs) and the health awareness status of sex workers in the state of West Bengal. Despite the fairly good awareness of HIV, information about other STIs and symptoms of these infections remains very sparse and can frequently result in the late diagnosis, inadequate treatment and increased spreading potential. The research highlights that the actualization of SDG 3 requires the adoption of rights-based and inclusive health policies, which should deal with structural inequalities, increase the community outreach and ensure the provision of stigma-free and accessible healthcare services. Recognizing and giving priority to the health demands of sex workers is critical to ensuring universal coverage to health and enhancing equity in the provision of public health.

Keywords: Sexually transmitted infection (STI), unseen exposure, health awareness, sex workers, sustainable development goals

Introduction

The STIs have been a health concern of particular interest to the population particularly the marginalized population such as sex workers in West Bengal. Despite the existing national HIV and reproductive health programs, majority of sex workers remain highly vulnerable because of the stigma that surrounds them, work safety, low health literacy and inaccessibility to quality healthcare systems. Despite the awareness campaigns, which have improved the knowledge on HIV, it lacks proper awareness on other STIs and their long term effects. This paper examines the gap between the ideal of policy delivery of universal health coverage and the facts of sex workers in accordance with the United Nations Sustainable Development Goal 3 (Good Health and Well-being). The research, in the examination of STI vulnerability and health cognizance suggests that the upcoming challenge involves implementing rights based and comprehensive without stigma healthcare methods, which would not abandon anyone en route to attain equitable populace health results. Background of the study

Despite the efforts made that are in alignment to the United Nations Sustainable Development Goal 3 (Good Health and Well-Being), the sex workers in West Bengal remain at high risk of STIs. Despite the fact that the awareness and prevention efforts by the National AIDS Control Organisation should help the society be more aware and prevent HIV transmission, the stigma of the area, medical and legal discrimination to restrict access to frequent testing and treatment are the reasons why the society does not improve. The behaviour of the customers also adds to the risk in that a high number of the clients demand unprotected sex or will not use condoms at the cost of their financial conditions. Thus, the exposition of STIs is founded on the deficiency of health understanding and also on social obstacles and inequality of power and, therefore, comprehensive and free healthcare is crucial within SDG 3.

Methodology

The research study will employ doctrinal research approach, including analysis of international law tools, national laws, constitution, committee reports and government policies. The study is founded on the primary and secondary sources, such as the international and national legislation, case law and official sources. Relevant academic literature and articles have also been taken into account. The analysis utilizes the statutory interpretation methods, the comparative analysis and the normative analysis as tools to detect the regulatory loopholes and to suggest the course of reforms. Also, other methods

of research that have been applied to buttress the doctrinal research include incident analysis, case studies and detailed case analysis.

Discussion and Result

Poor awareness towards Non-HIV STIs among Female Sex workers in Sonagachi, Kolkata

In such red light areas as Sonagachi in Kolkata, sex workers are quite educated in terms of HIV prevention due to developed interventions programmes. Other STIs such as syphilis and gonorrhea have little information on them. One of the female sex workers (32 years old), stated that she would use condoms with her clients all the time but had no knowledge of non-HIV STIs symptoms. When reproductive health complications arose, it was due to isolation of the disease at its late stage. The scenario presented in the given case demonstrates the lack of interconnection between the HIV-specific education and the comprehensive STI education, which means that the inclusive health literacy educational programs should be applied to the SDG 3 (Dutta and Banerjee, 2023, p. 114).

Racial Inequalities and Obstacles to Healthcare Access among Migrant Sex Workers in North 24 Parganas

A 28 year old migrant sex worker in North 24 Parganas was not willing to visit the public health facilities because she was afraid of being discriminated. She did not have a professional doctor; instead, she took informal drugs that were available in local pharmacies despite having the symptoms of being infected. The social stigma and judgmental attitude of health care providers discouraged formal treatment seeking behavior. The case shows that stigmas have a negative influence on the goal of universal health coverage and the obstacles to achieving equal access to healthcare as outlined by SDG 3 (Chakraborty and Saha, 2023).

Economic Risk and Uncertainty: Unsafe Sexual Intercourse in Female Sex Workers in Semi Urban West Bengal

One of the semi-urban regions of West Bengal, a 35-year-old sex worker described the case as follows: When she needs money, she could accord unprotected intercourse on a greater price. She was better exposed to STIs because she was economically dependent and had no other means of livelihood. As this example demonstrates, poverty and gender inequality not only clash with health risks but also that the STIs prevention initiative should be based on adding economic empowerment strategies to gain SDG 3 (Mukherjee and Roy, 2022).

Young People in Sex Work and poor Sexual Health Literacy in a West Bengal Border District

The new sex worker candidate was a West Bengal border district 19 year old girl who had little information on sexual health and reproductive rights. She failed to perceive the symptoms of STIs as something small and to be avoided later since she had not been exposed to awareness programs. The fact that people are in sex work at a very young age and that they do not have good health literacy predisposed them to vulnerability. As mentioned in the case, there is the necessity of having youth-specific intervention on the basis of sustainable health goals (Das & Ghosh, 2023).

STI Interventions in Kolkata that are peer-led

A community based institution in Kolkata provided peer education and testing of STIs and counseling. One of the sex workers who is aged 40 years stated that she is more enlightened and she visits health clinics frequently since she has been interacting with peer educators, her stigma has been lessened too. The case reflects the positive outcomes of rights-based and community-oriented healthcare systems and suggests the progress in the achievement of SDG 3 through the promotion of inclusive and reachable healthcare services (Sen & Bhattacharya, 2023).

Table 1: STI Vulnerability and Interventions among Sex Workers in West Bengal

Case Study	Location	Issue Identified	Impact on Health
Limited Awareness of Non-HIV STIs Among Female Sex Workers in Sonagachi, Kolkata	Sonagachi, Kolkata	High HIV awareness but limited knowledge of other STIs (syphilis, gonorrhea)	Delayed diagnosis and reproductive health complications (Dutta & Banerjee, 2023, p. 114)
Barriers to Healthcare Access Among Migrant Sex Workers in North 24 Parganas	North 24 Parganas	Stigma and discrimination in public healthcare facilities	Avoidance of formal treatment and reliance on informal medication (Chakraborty & Saha, 2023)
Economic Vulnerability and Risk Negotiation: Unsafe Sexual Practices Among Female Sex Workers in Semi-Urban West Bengal	Semi-urban West Bengal	Financial crisis leading to unprotected sex for higher payment	Increased exposure to STIs (Mukherjee & Roy, 2022)
Adolescent Entry into Sex Work and Low Sexual Health	Border district, West Bengal	Low health literacy and delayed treatment among young entrant	Increased vulnerability to STIs(Das & Ghosh, 2023)

Case Study	Location	Issue Identified	Impact on Health
Literacy in a Border District of West Bengal			
Peer-Led STI Interventions in Kolkata	Kolkata	Community-based peer education and STI services	Improved awareness, regular check-ups, reduced stigma(Sen & Bhattacharya, 2023)

Source: *Author’s own work based on a review of* Dutta & Banerjee (2023); Chakraborty & Saha (2023); Mukherjee & Roy (2022); Das & Ghosh (2023); and Sen& Bhattacharya (2023)

In the table, it has been indicated that female sex workers in West Bengal are vulnerable to STIs that are caused by a combination of several interrelated factors such as lack of knowledge about non-HIV STIs, stigma and discrimination in the health care facilities, poverty and its related economic hardship, forcing them to engage in risky practices and low health literacy among the new entrants. Such social and economic restrictions raise health risks and slow down treatment, whereas community-based and peer-led intervention is a positive contributor to health as it enhances awareness, decreases stigma and promotes frequent healthcare visits.

Legal Framework Protecting the Health of Sex Workers in India

Under the international law approach, the right to health, dignity and non-discrimination is entrenched in international human rights documents that have been adopted in the context of the United Nations such as the Universal Declaration of Human rights (1948) and the International Covenant on Economic, Social and Cultural Rights (1966) that acknowledged the right to the highest attainable standard of physical and mental health (United Nations, 1948; United Nations, 1966). Constitutional protection of equal standing before the law, freedom of occupation and right to life and personal liberty in India through Articles 14, 19(1)(g) and 21 of the Constitution of India is judicially broadened to allow Indians the right to live with dignity and receive healthcare services (Jain, 2019, p. 245). The Immoral Traffic (Prevention) Act, 1956 governs some of the elements of sex work, however, it has been frequently accused of allowing harassment and throwing weight to stigma (Immoral Traffic (Prevention) Act, 1956). Supreme court India judicial statements have empowered protection of sex workers: in Budhadev Karmaskar v. The Court of West Bengal affirmed that consensual adult sex workers had the right to equal protection and dignity and ordered police to stop harassing them (Budhadev Karmaskar v.). State of West Bengal, 2011), it is claimed that s.9(2) represents a restriction on the freedom of speech of the

press.<|human|>In *Aishwarya Adhikari v. State of West Bengal* (2011), it is argued that s.9(2) is a limitation on liberty of the press of speech. The Court of State of West Bengal and Ors the Court in the case against sexual offences and police practices under the ITA and the IPC resumed the review of the sexual offences and the police in a manner that further strengthened the procedural safeguards and human treatment of the sex workers (*Aishwarya Adhikari v.*). *State of West Bengal & Ors*, 2022). These international standards, constitutional provisions, legislative policies and judicial rulings will provide a solid legal basis that can support non-discriminatory and rights-based healthcare access to sex workers in line with SDG 3.

Conclusion and Recommendations:

Vulnerability to STIs in sex workers in West Bengal is associated with stigma, inequality and poor access to healthcare instead of individual risk. Although it has pledged to do so in the United Nations SDG 3, there are still loopholes in inclusive and rights-based health services. To be able to real progress, it is necessary to carry out system-wide reform, bringing marginalized voices into focus and making healthcare a reality. In order to reduce the vulnerability of sex workers to STIs and enhance health literacy among sex workers in West Bengal under Sustainable Development Goal 3 (Good Health and Well-being), the rights-based approach is necessary. The interventions also need to be extended beyond HIV-centered interventions and include education on all sexually transmitted infections, accessible and stigma-free healthcare services and reinforce peer-based community outreach programs. Economic capacity building and social protection programs should become a combination in order to curb high-risk behaviors caused by financial insecurity. Also, health education and early intervention strategies should be given priority to youths in order to improve the long-term quality of life. Government agencies, healthcare facilities and community based organizations need to work together to facilitate equal access to universal health coverage and sustainable health outcomes.

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CHAPTER

Access to Justice and Healing: Sustainable Rehabilitation of Acid Attack Survivors in West Bengal under SDG 16

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Abstract

Acid attacks are among the most atrocious gender-based violence where women are mostly the victims with the aim of killing, mutilating, or mutilating them in a permanent manner. Although the physical impact of it is catastrophic, the victims tend to have a more lasting psychological trauma, social stigma and identity loss. In India, even after the legislation has been enacted like the Sections 326A and 326B of the Indian Penal Code, judicial directives in *Laxmi v. State of Uttar Pradesh* is a severe socio-legal issue that is still a union of India and state victim compensation schemes. The National Crime Records Bureau records continuously show that West Bengal reports some of the worst cases of acid attacks and thus is a good location to study the access to justice and rehabilitation systems. The paper takes a policy and legal perspective to analyze legal provisions, judicial precedent and schemes of rehabilitation in West Bengal. It evaluates whether the compensation systems are sufficient, psychological counseling accessible and whether the victims of sexual violence can be reintegrated into the economy. The research concludes that timely compensation, institutional coordination and long-term psychosocial support have significant gaps in the legal framework, which is full of progressive intent. In line with Sustainable Development Goal 16, which supports access to justice and inclusive institutions, the paper holds that sustainable rehabilitation should go beyond financial support to include holistic institutional support, restoration of dignity and integration into

society. The delivery of meaningful access to justice and holistic rehabilitation is hence not only a welfare requirement but a constitutional and human right requisite that is important in the construction of inclusive and equitable societies.

Keywords: Acid Attack survivors, Access to Justice, Sustainable Rehabilitation, SDG16, Gender based violence, Rehabilitation.

Introduction

An acid attack is a planned terrorist attack whereby a corrosive liquid is employed as a weapon to permanently modify the body of another individual, usually the face, with an aim of disfiguring, disabling, or destroying identity, rather than injuring it. Historically, acid attacks were referred to as the vitriol attacks since the sulphuric acid was mostly referred to as oil of vitriol. In older legal and journalistic terms, such incidences were thus called vitriol attacks. This may be explained by chemistry that only flesh is burned by the acid, but what is crueler than it is physical. It may destroy the identity, self-confidence and self of a person that can be scarred, which no amount of medicine can help to heal fully. Acid attacks are also violence as well as grave infringement of essential human rights. The provision of access to justice and effective legal remedies to the survivors and the organizing of rehabilitation in line with Sustainable Development Goal 16, which is to achieve peaceful and inclusive societies, avail justice to everyone and establishing accountable institutions (United Nations, 2015).

Background of the Study

The National Crime Records Bureau (NCRB, 2023) noted that in 2023, the number of acid attacks in India had risen to 207 as compared to 202 in 2022 and 176 in 2021. The West Bengal state had the most (57) cases, which made up 27.5 per cent of the national figures. Others that followed were Uttar Pradesh (31), Gujarat (15), Rajasthan (11) and Odisha (11). The West Bengal has been registering high rates of acid attacks since 2018. In 2020, a young college girl in the Nadia district was assaulted with acid when she was asleep at home because she turned down advances of a man (The Times of India, 2020). After the Class 12 student rejected a marriage proposal in East Midnapore, she and her family were attacked (Hindustan Times, 2019). These attacks are not only physical tortures, but they are also efforts to control, punish and humiliate. Acid attacks are understood to be gender-based violence and infringement of human rights at the international level.

Methodology

The research study will employ doctrinal research approach, including analysis of international law tools, national laws, constitution, committee reports and government policies. The study is founded on the primary and secondary sources, such as the international and national legislation, case law and official sources. Relevant academic literature and articles have also been taken into account. The analysis utilizes the statutory interpretation methods, the comparative analysis and the normative analysis as tools to detect the regulatory loopholes and to suggest the course of reforms. Also, other methods of research that have been applied to buttress the doctrinal research include incident analysis, case studies and detailed case analysis.

Legal Framework on Acid Attacks in India

In its 226th report (2009) the Law Commission of India considered acid attacks as a special crime and has suggested special provisions under the penal laws, control of acid sales as well as the compensation of the victims and free treatment. According to the Justice J.S. Verma Committee Report (2013), acid attacks were gender crimes that need to be punished sternly with the responsibility of the state to rehabilitate them. In accordance with such recommendations, Section 326A and 326B were added to the Indian Penal Code. Section 326A sentenced acid attacks to no less than ten years of incarceration (and up to life imprisonment) and a fine adequate to cover medical costs. Section 326B punished the attempts with imprisonment of between five to seven years. A Victim Compensation Scheme has been put in place in section 357A of the Code of Criminal Procedure acknowledging that no justice is complete without financial rehabilitation. As mentioned in Section 124 of the Bharatiya Nyaya Sanhita (BNS), 2023 acid attacks are still major offences. In *Laxmi v. Union of India* (2014), the Supreme Court directed ordered to enhance strict control over the sale of acid and the identity verification of their buyers, forbid the sale of acid to minors, set a minimum of 3 lakh rupees compensation and free treatment in the hospitals. In *Parivartan Kendra v. Union of India* (2015) cited dignity and disability benefits, access to education and long-term rehabilitation instead of money.

Legal Mechanism in West Bengal

Acid attack victims in West Bengal are safeguarded by the Bharatiya Nyaya Sanhita, 2023. Subsection 124 criminalises attempts and acid attacks and provides harsh punishment. The regulation of acid sale is by licensing and compulsory record keeping. The sellers are required to check identity and keep purchase registers. These control systems are intended to guard against abuse.

Nevertheless, there are still gaps in implementation. Survivors are also characterized by delays in filing FIRs, ignorance on the compensation schemes and lengthy court proceedings.

Notable interventions of the judiciary in West Bengal are: Calcutta high court has also contributed a lot in enhancing the compensation and rehabilitation of acid attack victims. In *Piyali Dutta v. State of West Bengal & Ors.*, AIR 2017 Cal 345, the Court observed that a victim can not be deprived of compensation due to the introduction of victim compensation scheme after the fact and thus allowed application of updated schemes retrospectively and affirmed the idea that a procedural limitation could not override substantive justice. The Calcutta High Court in the *South 24-Parganas Acid Attack Case*, In Re: Acid Attack Victim (South 24-Parganas), AIR 2016 Cal 478, ordered payment of compensation of 3 lakh immediately and inspected against bureaucratic and administrative justifications and insisted that payment provided under Section 357A of the Code of Criminal Procedure should be timely and effective. Moreover, in *Paramita Bera & Anr. v. Union of India and Ors* AIR 2023 Cal 112, the Court granted increased compensation of 10.5 lakh rupees to a minor girl victim and her brother because it is important to consider that the severity of the injury and the age of the victim and long-term rehabilitation needs can affect the compensation given. Combined these rulings indicate that despite the existence of statutory measures, the courts frequently have to step in to obtain timely and sufficient relief and it demonstrates the defensive role that the High Court can play and still demonstrates gaps in administrative application.

The support mechanisms in West Bengal are: The West Bengal State Commission for Women (WBCW), which offers legal advice and counseling as well as help in seeking justice. The Swasthya Sathi Scheme is a scheme that provides a financial cover of medical treatment, including surgery and rehabilitation. State Government Rehabilitation Funds, are funds that offer financial compensation to enable the survivors to foot their medical bills and costs on reintegration. Non-governmental organizations, like Make Love Not Scars and local support groups provide professional training, psychological counseling and job assistance. Even with such mechanisms, most of the survivors have to fight a long legal battle to get compensation.

Result and Analysis

With the continuous judicial interventions, the real enforcement of compensation and rehabilitation patterns of acid attack survivors in West Bengal is uneven. The chain of district level events below demonstrates the

systemic delays, lack of psychosocial support and reintegration of the economy at the current framework.

Implementation Gaps in Compensation and Rehabilitation Mechanisms in West Bengal

Nadia Acid Attack Survivor (Post-2013 Reform Period)

In a case reported after the Criminal Law (Amendment) Act, 2013, the survivor received initial emergency medical care but faced long delays in receiving full compensation under the West Bengal Victim Compensation Scheme framed under Section 357A CrPC (Criminal Law (Amendment) Act, 2013; West Bengal Victim Compensation Scheme, 2017). Supreme Court guidelines mandating minimum compensation and regulation of acid sales were laid down in *Laxmi v. Union of India*, (2014) 4 SCC 427. However, NCRB data and civil society documentation indicate persistent delays in compensation disbursement and lack of coordinated psychosocial rehabilitation (NCRB, *Crime in India*, 2016–2019).

Malda Minor Rape Survivor (POCSO Case)

In a POCSO case from Malda district, compensation approval was reportedly delayed due to procedural verification between police authorities and the District Legal Services Authority (DLSA), reflecting structural bottlenecks under Section 357A CrPC and the POCSO Act, 2012 (NCRB, *Crime in India*, 2018–2020). The Supreme Court emphasized immediate interim compensation and confidentiality in child sexual assault cases in *Nipun Saxena v. Union of India*, (2019) 2 SCC 703, yet implementation gaps at the district level continue to be reported in Legal Services Authority reports.

Birbhum Sexual Violence Case

In the Birbhum violence case (2022), arrests were made promptly; however, rehabilitation measures were largely confined to interim financial assistance (NHRC Proceedings in Birbhum Violence Case, 2022; *The Hindu*, March 2022). The broader issue of inadequate restorative rehabilitation despite criminal prosecution reflects concerns raised in *Ankush Shivaji Gaikwad v. State of Maharashtra*, (2013) 6 SCC 770, where the Supreme Court stressed mandatory victim compensation under Section 357A CrPC.

Murshidabad Acid Attack Survivor

Despite the Supreme Court's directives in *Laxmi v. Union of India*, (2014) 4 SCC 427, requiring minimum compensation and regulation of acid sales, district-level implementation delays in compensation disbursement have been reflected in NCRB statistical trends and Legal Services Authority reports

(NCRB, *Crime in India*, 2017–2021; West Bengal State Legal Services Authority Reports). Survivors often relied on partial funding for surgeries, with limited institutionalized vocational rehabilitation.

Kolkata Domestic Acid Assault Case

In reported domestic acid assault cases in Kolkata, compensation was sanctioned under the West Bengal Victim Compensation Scheme but released in phases, indicating administrative delay (West Bengal Victim Compensation Scheme, 2017; AIR 2016 Cal 478). The Calcutta High Court in *In Re: Acid Attack Victim (South 24-Parganas)*, AIR 2016 Cal 478, emphasized that compensation must not be hindered by bureaucratic procedures, highlighting recurring implementation failures.

Across these incidents, governmental shortcomings manifest not as outright denial of statutory relief but as delayed compensation, fragmented institutional coordination, insufficient structured psychological counseling and weak economic reintegration mechanisms (NCRB, *Crime in India*, 2016–2022; NHRC, 2022; AIR 2017 Cal 345; AIR 2016 Cal 478). Although the legal framework including Section 357A CrPC, the POCSO Act and Supreme Court directives reflects progressive intent, effective rehabilitation frequently depends on judicial intervention or civil society support, exposing systemic weaknesses in holistic survivor rehabilitation in West Bengal.

Conclusion and Recommendations

Acid attacks are the gross infringement of human rights and human dignity. Legal provisions in West Bengal include West Bengal rehabilitation schemes, guidelines of the Supreme Court and the Bharatiya Nyaya Sanhita, which offers a framework of the state. Nonetheless, there are still implementation lapses and social obstacles. Justice does not simply mean punishing the wrongdoers; it also means regaining dignity, availing rehabilitation as well as acceptance of them in society.

Coexistence of legal implementation and SDG 16 make sure that the victims are not only compensated but also make them powerful and able to restore their lives and be full citizens. The following suggestions are recommended:

- The stricter implementation of sales of the acid regulations is necessary.
- The compensation processes have to be simplified and shortened.
- Emergency response systems should be provided with medical and

psychological care.

- Patriarchal attitudes should be challenged in the community awareness programs.
- Helpline and legal assistance services that would assist victims in the processes should be established.
- Cooperation between the non-government organizations and the governments should be enhanced.

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