

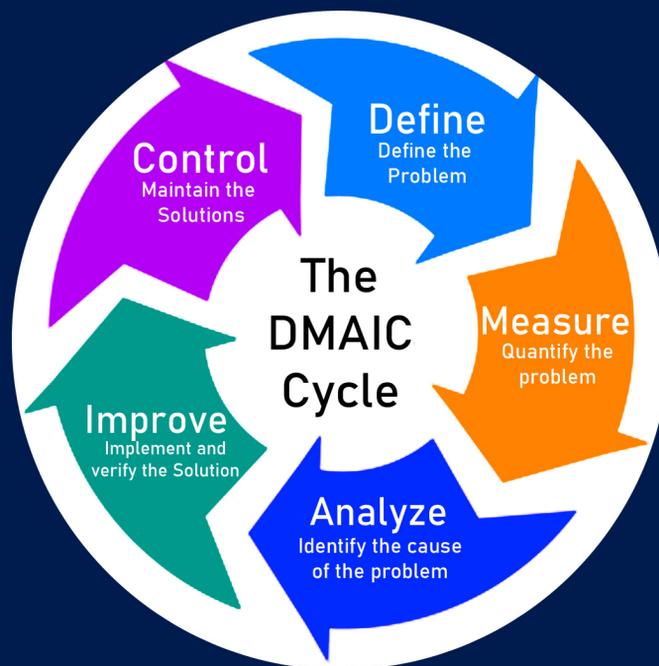
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Plot. No-622, Palaspur, Chhatabar, Khordha, Bhubaneswar-752054, Odisha.

Mob. No. 9437402223, 9937102759, 9337397727.

Email: principal@iimsodisha.in,

Web: www.ashaakiranngroup.com

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Plot No- 622, Palaspur, Chhatabar, Khordha, Bhubaneswar-752054, India.

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It gives me immense pleasure to bring out the **Journal of AKGI Research Review (AKGIRR)**, our scholarly journal referred Bi- annual/ Semiannual (Twice a year - April and October) journal of **Ashaa Kirann Group of Institutions (AKGI)**, Bhubaneswar, a top notch promising premier professional, Information Technology, Technical and Health Science in the country. The issues so far have been incited by the multidisciplinary communities & the corporate leaders. Our endeavor to disseminate the novel dimensions of emerging thinking & research in the field of Academics.

The Academics landscape is progressively changing, so as the thinking as well as practice. Considering this view, the current issue projects some articles chew over the same domain. This is originating on different facets of multidisciplinary innovative thoughts pertaining to different countries, diverse areas & emerging practices in Global arena. Given the context, the articles presented in this volume will have consequential applied value for the readers.

I look forward to the continued co-operation in terms of contributing articles perennially.

Reader's feedback is always welcome!

Wish you a value-laden retrospection!!!

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FROM EARTH TO SPACE: THE PROMISE OF GRAPHENE-BASED PROTECTIVE COATINGS FOR NEXT-GENERATION AEROSPACE AND SPACE APPLICATIONS.

Author-Rajata Kumar Mansingh¹, Raj Kishore Mishra², Tapan Dash³

¹Centurion University of Technology and Management, Odisha, India

²Maharishi College of Natural Law, Saheed Nagar, Bhubaneswar, Odisha, India

³International PranaGraf Mintech Research Centre (IGMRC), Bhubaneswar, Odisha

Abstract

Graphene-based Nano coatings have emerged as a revolutionary nanomaterial for addressing critical challenges in the aerospace and space industries. This article explores the unique properties of graphene, including its strength, thermal conductivity, electrical conductivity, and corrosion resistance, and how these attributes make it an ideal candidate for protective coatings in extreme environments. We focused on the current and outstanding applications of graphene coatings in aerospace and space exploration, highlighting their impact on fuel efficiency, durability, and system protection. Additionally, the article also discusses the challenges involved in scaling up graphene production and integrating it with existing aerospace materials, and provides insights into the future industrial scope and finds directions of graphene-based coatings in these sectors.

Keywords: Graphene, Protective Coatings, Aerospace Applications, Space Applications

1. Introduction

The aerospace and space sectors are progressively depending on sophisticated nanomaterials and relevant technologies to satisfy the rising requirements for performance, efficiency, and safety in extreme conditions. There are several limitations in the conventional materials when they come to meeting the diverse and often conflicting requirements of strength, lightness, corrosion resistance, and thermal management. As these sectors look toward the next generation of technologies, the incorporation of graphene-based Nano coatings has gained significant attention due to the outstanding properties of graphene [1, 2]. Graphene, a single-atom-thick layer of carbon arranged in a hexagonal lattice. It is recognized as one of the most remarkable materials ever discovered. Its unique combination of mechanical strength, conductivity, flexibility, and chemical stability makes it a promising potential candidate for creating next generation coatings that can enhance the performance of aerospace and space systems. Its high tensile strength (~130 GPa), superior thermal conductivity (>5000 W/mK), and exceptional permeability to gases make it ideal for next-generation surface protection. When applied as a Nano coating, graphene forms an ultra-thin,

continuous layer that can shield substrates from harsh operational conditions such as high temperature, vacuum exposure, and radiation bombardment-common in both aircraft and spacecraft systems. Starting from protecting aircraft exteriors to shielding spacecraft from harsh space conditions, graphene-based coatings are severely poised to play a pivotal role in the next wave of technological advancements particularly in these sectors. This article provides an in-depth examination of graphene-based Nano coatings and their potential to revolutionize aerospace and space applications. We have taken systematic steps to explore their key properties, the current state of research, and future prospects for their integration into aerospace systems.

2. Properties of Graphene for Protective Coatings

Graphene's outstanding properties make it an ideal nanomaterial for protective coatings in aerospace and space applications. These properties can be categorized into mechanical, thermal, electrical, and chemical characteristics.

2.1. Mechanical Strength and Durability

One of the most remarkable properties of graphene is its superior mechanical strength. It is over 200 times stronger than steel by weight; however, it is incredibly light. This unique strength-to-weight ratio makes graphene-based coatings extremely effective at enhancing the durability of surfaces exposed to extreme critical forces, such as the high-speed airflow around aircraft or the harsh conditions of space. Graphene coatings have significant ability to improve the wear resistance of materials, reduce the likelihood of cracks, and increase the overall lifespan of aerospace components.

2.2. Thermal Conductivity

Graphene shows extraordinary thermal conductivity, which is crucial for critical applications where heat dissipation is considered as primary concern. Generally, in space, for instance, temperatures can fluctuate dramatically between the cold vacuum of space and the intense heat generated during atmospheric re-entry in the space. Graphene coatings can promote effective distribution and dissipation of heat, which can protect overheating of sensitive components in aerospace and space applications. This property is particularly important for spacecraft heat shields, which are exposed to extreme temperatures during re-entry.

2.3. Electrical Conductivity

Graphene is considered is an excellent conductor of electricity. This makes graphene-based coatings are ideal for supporting electromagnetic shielding and protecting sensitive electronics from radiation and interference and other harmful radiations. For spacecraft, graphene coatings can be used to prevent electronics from solar radiation, cosmic rays, and

electromagnetic pulses (EMPs) that could disrupt communication and data transmission systems.

2.4. Corrosion Resistance

The aerospace industry faces significant challenges related to corrosion, particularly in materials exposed to moisture, salt, and extreme environmental conditions. Graphene's inherent resistance to corrosion makes it a highly effective barrier material. When applied as a coating, graphene can prevent corrosion by creating an impermeable layer that protects the underlying material from environmental degradation.

2.5. Self-Healing Properties

Recent advancements in graphene research have explored the possibility of creating self-healing graphene-based composites suitable for aerospace and space technological applications. These materials can "repair" small cracks or damage that might otherwise compromise the integrity of the coating material. This ability to self-repair is very much needed for space missions, where access for maintenance is limited and the cost of repairs is considered as high.

3. Applications of Graphene-Based Coatings in Aerospace and Space

Graphene-based coatings are finding various applications across both the aerospace and space sectors, each with unique challenges that graphene can address.

3.1. Aircraft Protection

In aerospace, graphene coatings are being developed for use in aircraft exteriors, where they can provide multiple benefits.

- **Drag Reduction:** Graphene's smooth surface reduces drag, improving fuel efficiency and overall performance. The enhanced aerodynamic behaviour of graphene-based coated aircraft surfaces can lead to significant reductions in fuel consumption in these sectors.
- **Corrosion Resistance:** Aircraft are generally exposed to harsh environmental conditions, including saltwater and extreme weather. Graphene coatings can be applied to protect and prevent from corrosion and enhancing the longevity of the aircraft systems.
- **Surface Hardness and Scratch Resistance:** The unique hardness of graphene-based coatings makes them resistant to scratches, which are common on aircraft surfaces due to exposure to high-speed airflow, debris, and environmental contaminants and harsh challenging conditions.

3.2. Spacecraft Protection

In the space industry, graphene-based coatings are being focused for several critical applications.

- **Heat Shields:** The graphene has ability to withstand high temperatures makes it a perfect candidate for use as a heat shield for re-entry vehicles in space systems. Its ability to dissipate heat helps to prevent the degradation of spacecraft components during atmospheric re-entry, where temperatures can exceed 1,500°C (2,732°F).
- **Micrometeoroid and Orbital Debris (MMOD) Protection:** Spacecraft and satellites in low Earth orbit are constantly at risk from various challenges such as collision with micrometeoroids and space debris. Mechanical strength of graphene provides to enhance protection from these impacts, which could otherwise cause catastrophic damage to spacecraft.
- **Radiation Shielding:** Space radiation shows a significant hazard to both electronics and human health. Graphene-based coatings can provide adequate protection by absorbing and scattering harmful radiation, shielding sensitive electronics from space weather events like solar flares and cosmic rays.
- **Self-Healing Capabilities:** Long-duration space missions demand advanced materials that can withstand harsh conditions without frequent maintenance. The self-healing properties of graphene-based coatings could effectively extend the lifespan of spacecraft by automatically repairing small damage caused by radiation, impacts, or wear.

4. Challenges and Future Directions

Despite its promising important potential, there are still several challenges exist that must be addressed before graphene coatings can be widely adopted in aerospace and space application industries.

4.1. Scalability and Cost

The production of graphene at large scale is still a costly and complex process. While methods such as chemical vapour deposition (CVD), liquid-phase exfoliation are advancing and mechanical milling, scaling these processes to meet the demands of aerospace manufacturing remains a significant challenge. The high production cost could constraint the widespread use of graphene-based coatings, especially for commercial applications.

4.2. Integration with Other Materials

Aerospace components are often composed of various materials, including metals, composites, and ceramics. Integrating graphene coatings with these diverse materials, while ensuring compatibility and maintaining the desired performance characteristics, is a key challenge. Researchers are working on developing hybrid materials that combine graphene with other substances to improve adhesion, durability, and overall effectiveness.

4.3. Long-Term Durability in Extreme Environments

While graphene has demonstrated excellent potential in durability in laboratory

settings, more research is needed to understand how it will perform over long periods in the extreme conditions of space and high-altitude environments. The impact of prolonged exposure to radiation, microgravity, and other factors on graphene-based coatings is still an potential area of active investigation.

5. Conclusion

Grapheme-based Nano coatings can be considered as an alternate and excellent material for next-generation application in aerospace and space technologies. The combination of graphene's exceptional mechanical strength, thermal conductivity, electrical properties, and corrosion resistance extends significant protection for a wide range of aerospace components. From improving fuel efficiency and durability in aircraft to protecting spacecraft from the harsh conditions of space, graphene coatings have potential to play a critical role in shaping the future of these industries. As research continues and production methods become more cost-effective, the use of graphene in aerospace and space applications is hopefully to expand, paving the way for the next generation of high-performance materials. The promise of graphene-based coatings is not just a technological advancement-it is a road map toward safer, more efficient, and more durable aerospace and space systems.

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**INFLUENCE OF CORPORATE CULTURE AND CORPORATE PERFORMANCE
ON THE ENVIRONMENTS OF INNOVATION: A STUDY.**

Author- Nibedita Nanda¹, Bhimasen Swain², Karunakar Patra³

¹Research Associate, Biju Patnaik University of Technology, Odisha

²Ashaa Kirann Group of Institutions, Bhubaneswar

³Rourkela Institute of Management Studies, Rourkela.

Abstract

This study proposes an integrated approach to achieving organizational excellence by aligning corporate culture, innovation, and performance, with a focus on the Rourkela Steel Plant, a public-sector enterprise in Odisha. Adopting a culture-based perspective, the research examines how internal values and practices influence outcomes. Structural equation modeling and regression analysis were used to analyze the data. The results reveal that a positive corporate culture fosters employee pride and ownership, which in turn drives innovation and enhances overall performance. The study concludes that both culture and innovation are critical drivers of organizational excellence.

Keywords: Organizational Culture, Corporate Performance, Innovation Environment, Denison Organizational Culture Model

Introduction

Corporate culture is widely recognized as a critical determinant of organizational success and a foundation for sustainable competitive advantage (Kenny, 2012). It plays a vital role in aligning diverse cultural elements, particularly within large business conglomerates. According to Idris et al. (2015), effective cultural integration facilitates improved communication and enhances organizational performance. Similarly, Lee and Gaur (2013) argue that a strong and cohesive culture significantly boosts productivity and operational efficiency. Broadly defined, corporate culture encompasses the shared behaviors, values, and underlying assumptions of individuals within an organization. It is shaped by the company's mission, vision, norms, and rules, and is transmitted to new members as a framework for perceiving, thinking, and behaving within the organizational environment.

Literature Review

According to Flamholtz and Randle (2012), an effective corporate culture is a fusion of a strong and positive culture. In a strong organizational culture, members consistently behave in alignment with the company's core values. A positive culture, on the other hand, is characterized by employees' clear understanding and shared commitment to corporate objectives and values across all levels of the organization.

Gibbs (2012) highlights the reciprocal influence between corporate culture and the wider community. Since employees are members of the broader society, societal values can influence corporate culture through these individuals, thereby embedding community norms within the organization.

The relationship between corporate culture and innovation has been widely studied, yet the diversity of cultural variables has led to a fragmented understanding of what constitutes an “innovation culture.” As Buschgens et al. (2013) argue, management practices require a structured framework to determine which cultural attributes foster innovation and to assess whether a given culture effectively facilitates coordination and innovation. Such a framework should enable the categorization of cultural values, support meaningful comparisons, and clarify their connection to organizational innovation.

Innovation is a critical driver of success in the steel industry. One of the key enablers of innovation is corporate culture, as it shapes employee behavior and can foster acceptance of innovation as a core organizational value. Schuldt and Gomes (2020) emphasize the need to deepen the understanding of the interconnections between corporate culture, innovation, and corporate performance.

This paper aims to conceptualize, measure, and examine various dimensions of organizational culture and their impact on corporate performance. A review of extensive scholarly literature reveals that corporate culture significantly influences organizational outcomes. Improvements in corporate culture are often accompanied by enhanced performance, suggesting that cultivating an effective industrial culture is essential for achieving business excellence (Yasas, Lakmini, & Ruwan, 2020).

The Role of Corporate Culture in Corporate Performance:

Most definitions of corporate culture reinforce common assumptions about how culture influences employee behavior (Schein, 1984). However, Schein emphasized that the nature of corporate culture is far more complex and plays a vital role in an organization’s success. He described corporate culture as dynamic and evolving—capable of being learned, transmitted, and reshaped over time.

Schein's structural model of organizational culture consists of three interrelated levels: basic underlying assumptions, espoused values, and artifacts (observable elements). At the most visible level, culture is expressed through symbols, rituals, and artifacts. While these are easily seen, they may not fully reveal the deeper meaning of the culture. In contrast, at the least visible level lie the fundamental values and assumptions that are taken for granted. These unconscious beliefs form the true essence of a corporate culture and often explain latent behaviors within the organization. Together, these levels shape a framework that binds the values and behaviors of organizational members.

Building on this foundation, O'Reilly and Chatman (1996) described corporate culture as a social control mechanism that guides and standardizes patterns of values, beliefs, and behaviors among members of an organization. Carson (2005) supported this view by referencing McGregor's Theory X, which posits that employees inherently need external control and direction to perform effectively.

Expanding on Schein's model, Homburg and Pflesser (2000) contributed to the theoretical development by exploring the link between corporate culture and performance outcomes. Their research highlighted the significance of observable artifacts—such as organizational practices and symbols—in influencing employee behavior, particularly in responding to customer needs and driving the overall economic performance of the firm.

Denison Corporate Culture Model

The Denison and Mishra (1995) model provides a well-established theoretical framework for understanding how corporate culture impacts organizational effectiveness. Their research identified positive correlations between specific cultural traits and both subjective (e.g., employee satisfaction) and objective (e.g., profitability, quality, sales growth) performance indicators. This model demonstrates that a strong, well-aligned corporate culture significantly contributes to improved organizational outcomes across various dimensions, including customer satisfaction, financial success, and overall effectiveness.

While it is widely acknowledged that corporate culture influences organizational performance, Lynham (2000) emphasizes that developing a robust theoretical hypothesis often requires the integration of multiple research strategies. This creates an opportunity for qualitative approaches to complement quantitative analyses by offering deeper insights into the nuances and underlying variables that shape the culture–performance relationship.

Accordingly, this study adopts a qualitative perspective to explore and expand the understanding of how organizational culture determinants are perceived to influence performance, particularly within the context of the Rourkela Steel Plant. The research question guiding this investigation is: "How are organizational cultural determinants perceived to influence organizational performance within a public-sector enterprise?"

To address this question, the study references the Denison Culture Survey, a diagnostic tool designed to assess the cultural dynamics of an organization in relation to workforce behavior and performance outcomes. Denison's model identifies four key cultural traits; each associated with specific management practices and organizational behaviors:

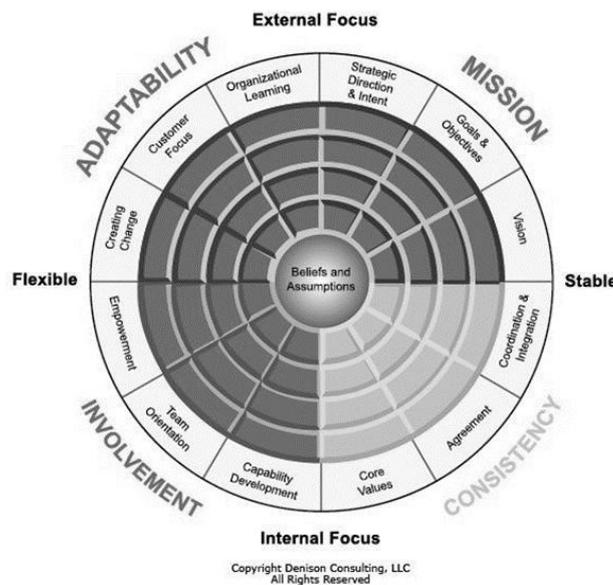
1. Involvement (Internal Focus)
 - Empowerment
 - Team Orientation
 - Capability Development

- 2. Consistency (Internal Focus)
 - Core Values
 - Agreement
 - Coordination & Integration
- 3. Adaptability (External Focus)
 - Creating Change
 - Customer Focus
 - Organizational Learning
- 4. Mission (External Focus)
 - Strategic Direction & Intent
 - Goals & Objectives
 - Vision

These four traits are grouped under two dimensions:

- Internal focus and integration (Involvement and Consistency)
- External focus and differentiation (Adaptability and Mission)

Each of the 12 indices within the model corresponds to specific management practices that reflect the organization's culture and its capacity to perform effectively. This model provides a useful framework for examining how cultural attributes may serve as drivers-or inhibitors-of performance, particularly in complex, hierarchical environments like those in public-sector enterprises. Its application to the Rourkela Steel Plant offers a pathway to identifying latent variables that influence workforce engagement, innovation, and performance outcomes.



The Denison Culture Survey

The Denison Culture Survey is a core component of the broader Denison Organizational Culture Model, developed by Daniel Denison and first implemented in 1990. It serves as a diagnostic tool designed to help organizations assess and improve their cultural dynamics in relation to performance outcomes. The model also includes the Leadership 360 Development Survey, which focuses on individual leadership behaviors within the same cultural framework. Together, these instruments offer a comprehensive approach to evaluating both organizational and leadership effectiveness.

The Denison model is structured around four key cultural traits: Mission, Adaptability, Involvement (Participation), and Consistency (Uniformity). These traits are arranged in a four-quadrant framework, reflecting a balance between internal versus external focus and flexibility versus stability.

Each of the four traits is measured through three managerial practices, making a total of 12 indices. These indices are assessed through a set of standardized survey questions, with each managerial practice represented by four questions. This structured approach allows for a quantitative evaluation of the organization's culture across multiple dimensions.

In addition to diagnosing the current cultural state, the survey also supports organizations in identifying strategic directions for improvement. It highlights areas where corrective actions may be necessary and guides leadership in aligning cultural practices with performance goals.

Methodology, Research Design and Data Collection

This study employed a descriptive and quantitative research design to investigate the relationship between corporate culture and corporate performance, with particular emphasis on the mediating role of innovation. The primary objective was to assess how various dimensions of organizational culture influence performance outcomes, both directly and indirectly through innovation. Primary data was collected using a structured questionnaire administered to employees of the Rourkela Steel Plant in Odisha. The questionnaire comprised both closed-ended and Likert-scale items, designed to capture respondents' perceptions of key cultural dimensions (as defined by models such as Denison's) and their impact on innovation and overall corporate performance. The use of standardized questions ensured consistency in data collection and facilitated quantitative analysis.

The questionnaire was structured into two main sections. The first section focused on assessing cultural traits-involvement, consistency, adaptability, and mission-as outlined in the Denison Organizational Culture Model. These traits were operationalized through specific items designed to measure employees' perceptions of the organization's cultural environment.

The second section examined key performance indicators, including productivity, profitability, employee satisfaction, and innovation outcomes. These indicators were selected to provide a multidimensional view of organizational performance from the perspective of internal stakeholders.

To ensure a comprehensive and representative understanding of the organization's cultural dynamics, the survey targeted a cross-section of employees, including executives, middle managers, and operational staff. This stratified approach facilitated the capture of diverse insights from multiple hierarchical levels within the Rourkela Steel Plant, enhancing the reliability and depth of the findings.

Data Analysis

To examine the influence of organizational culture on corporate performance, regression analysis was employed. In this model, corporate performance served as the dependent variable, while the four key dimensions of organizational culture—involvedness, consistency, adaptability, and mission—were treated as independent variables. The model's explanatory power and statistical significance were evaluated using the coefficient of determination (R^2), F-test, and p-values. These metrics provided insights into how well the cultural dimensions predicted variations in performance outcomes.

In addition to regression analysis, Structural Equation Modeling (SEM) was utilized to validate causal relationships among organizational culture, innovation (as a mediating variable), and corporate performance. SEM offered a more nuanced and holistic understanding of the pathways through which cultural traits influence innovation, and how innovation, in turn, contributes to enhanced organizational effectiveness. This dual-method approach strengthened the robustness of the findings and provided empirical support for the proposed conceptual framework.

Mixed-Methods Approach and Data Handling

In addition to quantitative analysis, the study incorporated qualitative observations through informal interviews with selected employees. This mixed-method approach enabled the triangulation of findings, thereby enhancing the validity and depth of the conclusions regarding the relationship between corporate culture and performance.

The primary data collection employed a structured survey design, with questionnaires divided into two key sections: corporate culture and corporate performance. Responses were compiled using Microsoft Excel and subsequently analyzed using regression techniques, where cultural dimensions served as the independent variables and performance metrics as the dependent variables. This integrated methodology allowed for a comprehensive examination of how cultural factors influence organizational outcomes.

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	Change Statistics			
						F Change	df1	df2	Sig. F Change
1	.994 ^a	.988	.984	7.98543	.988	245.881	1	3	<.001

a. Predictors: (Constant), CC

b. Dependent Variable: CP

The R column represents the multiple correlation coefficient, which measures the strength of the relationship between the observed and predicted values of the dependent variable. An R value of 0.994 indicates a very high level of prediction accuracy by the regression model.

The R Square column, also known as the coefficient of determination, quantifies the proportion of variance in the dependent variable that can be explained by the independent variables. An R Square value of 0.988 suggests that approximately 98.8% of the variability in corporate performance is accounted for by the four dimensions of organizational culture, demonstrating a strong explanatory power of the model.

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15679.149	1	15679.149	245.881	<.001 ^b
	Residual	191.301	3	63.767		
	Total	15870.450	4			

a. Dependent Variable: CP

b. Predictors: (Constant), CC

In the ANOVA table, the F-ratio tests whether the overall regression model provides a good fit for the data. The results indicate that the independent variables statistically significantly predict the dependent variable, with an F-value of 245.881 and a p-value less than 0.0005. This confirms that the regression model is a strong and reliable fit for explaining variations in corporate performance.

Conclusion

The findings of this study underscore the critical role of corporate culture and innovation in enhancing corporate performance. By cultivating a positive workplace culture, organizations can foster a strong sense of pride and ownership among employees, which translates into improved performance outcomes. Additionally, emphasizing innovation enables companies to remain competitive and adapt effectively within today's complex and rapidly changing business environment.

Through the application of structural equation modeling and regression analysis, this research has empirically demonstrated the significant influence of corporate culture and innovation on performance, particularly within the context of a public-sector enterprise such as the Rkl. Steel Plant.

Going forward, it is essential for organizations to embed these factors into their strategic planning and management practices to sustain long-term success and relevance. By doing so, organizations can position themselves as industry leaders and generate enduring value for their stakeholders.

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ADVANCES IN AI-POWERED PRECISION MEDICINE FOR THERAPEUTICS OF T2DM THROUGH *In-silico* AND AI/ML-BASED DRUG DESIGNING APPROACHES

Author-Chandra Sekhar Tripathy¹,

Rina Kumari², Tatekalva Sandhya³, Santosh Kumar Behera^{2*}

¹Department of Botany, School of Applied Sciences,

Centurion University of Technology and Management, Bhubaneswar, Odisha, India.

²Central Instrumentation Facility,

National Institute of Pharmaceutical Education and Research,

Ahmedabad, Gandhinagar, PIN-382355, Gujarat, India,

³Department of Computer Science,

Sri Venkateswara University, Tirupati, 517502, AP, India.

Abstract

Type 2 diabetes mellitus (T2DM) is a multifactorial metabolic disorder marked by insulin resistance, progressive β -cell dysfunction, and cardiometabolic complications. Despite an expanding armamentarium of antidiabetic agents, therapeutic efficacy is often limited by heterogeneity in disease mechanisms, off-target liabilities, and suboptimal long-term durability. Conventional approaches to T2DM care usually overlook the multifactorial factors like genetic, environmental variables and food habits for each patient. However, new advances in personalized medicine and genetics are transforming our understanding and approaches in T2DM management.

In the current arena artificial intelligence (AI) driven *In-silico* drug design provides a scalable, hypothetical framework to accelerate early detection of pre diabetes, discovery of safer, more effective personalized T2DM therapeutics. This review unzips the state-of-the-art computational flow chart strategy that could span the potential targets and drug consumption of an individual that revealed from multi-omics datasets; ligand-based modeling (pharmacophore elucidation, QSAR); structure-based design (docking, free-energy calculations, molecular dynamics); and early risk triage via machine-learned ADMET and poly-pharmacology prediction. The current review concludes with future directions: foundation-model chemistry, cryo-EM-informed dynamics, QM/MM refinement, federated learning for patient-level stratification, and digital-twin modelling for precision therapy. Collectively, *in-silico*, and AI-powered precision medicine followed by *in-vitro*, *in-vivo*, and clinical approaches could shorten the T2DM therapeutic timelines, reduce attrition, and enable mechanism-guided management of T2DM.

Keywords: Artificial Intelligence, Drug Design, Insulin Resistance, Precision

Medicine, Type 2 Diabetes Mellitus.

Introduction

Type 2 diabetes mellitus (T2DM) has arisen as a widespread chronic metabolic illness characterized by high blood glucose (hyperglycemia) and the three Ps, namely polydipsia, polyphagia, and polyuria. Hyperglycemia and insulin resistance are two hallmarks of T2DM, a chronic metabolic condition that represents a major risk to human health (1). The condition is primarily characterized by insulin resistance, impaired pancreatic β -cell function, and abnormal hepatic glucose output, which collectively disrupt glucose homeostasis. Importantly, T2DM is not merely a disease of dysregulated blood sugar levels but a systemic disorder associated with obesity, dyslipidemia, cardiovascular disease, nephropathy, neuropathy, neurological diseases, retinopathy and diabetic foot (2). These comorbidities impose a significant economic and social burden on patients, healthcare systems, and societies worldwide (3). A person with T2DM may have associated diseases like cardiovascular disease, hypertension, obesity, affecting kidneys, eyes, nerves, and feet, and can also increase the risk of Alzheimer's disease, certain cancers, sleep apnea, and depression. T2DM represents a complex, heterogeneous, and progressive metabolic disorder that has emerged as one of the most global health challenges of the 21st century and Diabetes-related global public health intervention is urgently needed to be addressed. According to the most recent International Diabetes Federation (IDF) study, the number of people aged 20 to 79 with DM globally has reached 537 million (10.5%), with T2DM accounting for more than 90%, and the number of patients is expected to reach 783 million (12.2%) by 2045 (4) and 852.5 million by 2050 (5). Diabetes is most prevalent in China, with around 148 million people affected, followed by India with 89.8 million in 2024. These two countries have the highest and second-highest diabetes burdens, respectively (IDF Diabetes Atlas 11th edition 2025). If the current rate of T2DM prevalence continues, India would eventually surpass China and become the world's diabetic hub (6).

In the clinical venture worldwide, many FDA approved antidiabetic pharmaceutical medications are prescribed to the patients with T2DM. Current therapeutic strategies for T2DM include insulin secretagogues (sulfonylureas), insulin sensitizers (metformin, thiazolidinediones), incretin-based therapies (DPP-4 inhibitors, GLP-1 receptor agonists), and sodium–glucose cotransporter-2 (SGLT2) inhibitors. While these agents improve glycemic control and reduce complications, however several limitations persist, such as adverse drug reactions, variable patient response, declining efficacy with disease progression, and inadequate management of multifactorial pathways driving T2DM. Consequently, there is a critical need for next-generation therapeutic interventions that are safer, more effective, and patient-tailored.

In this context, artificial intelligence (AI) driven *In-silico* drug design has emerged as

a transformative paradigm, complementing experimental and clinical research. *In-silico* approaches harness computational tools including molecular docking, pharmacophore modelling, molecular dynamics, quantitative structure–activity relationship (QSAR) modeling, precision network pharmacology, and AI to identify, optimize, and prioritize drug candidates. These methods accelerate discovery pipelines, minimize experimental costs, and enable systematic exploration of vast chemical spaces with high predictive accuracy (7). Moreover, the integration of multi-omics datasets, machine learning, and systems biology facilitates precision medicine by aligning therapeutic design with genetic and metabolic signatures of individual patients.

This review aims to provide a comprehensive overview of AI driven *in-silico* drug design which contributes and accelerates the discovery and development process of novel therapeutics for T2DM. It highlights computational strategies, key molecular targets, case studies involving synthetic and natural compounds, and the role of AI in advancing precision therapy. The discussion also addresses challenges and limitations, followed by insights into future research directions.

Precision medicine and artificial intelligence in T2DM

Artificial intelligence and precision medicine have the potential to revolutionize the medical industry. Recent studies indicate that translational research exploring this convergence will help address the most difficult problems in precision medicine, especially those where individualized diagnosis and prognosis will be made possible by the combination of non-genomic and genomic determinants with patient symptoms, clinical histories, and lifestyle data (8). There is significant heterogeneity among various T2DM patients or patient groups that trials based on patient cohorts may overlook, leading to incorrect conclusions about the effectiveness of diagnoses or therapies in individuals. Due to these mistakes, some medications have been reported to be successful in only one out of every twenty-four patients. The creation of more effective diagnostics and treatments based on high-quality evidence collected from individuals rather than cohorts, taking into account their personal history, genome, environment, lifestyle, physiology, and behaviors, has sparked an unprecedented interest in personalized medicine, also known as precision medicine (9). Precision medicine bioinformatics is being improved by AI, which is revolutionizing the processing of omics data, including metabolomics transcriptomics, proteomics, and genomes (10). It can be divided into several phases, including AI-augmented personalized health management, early screening, exact diagnosis, and precise clinical therapy, which includes both patients and healthy people (Fig1).

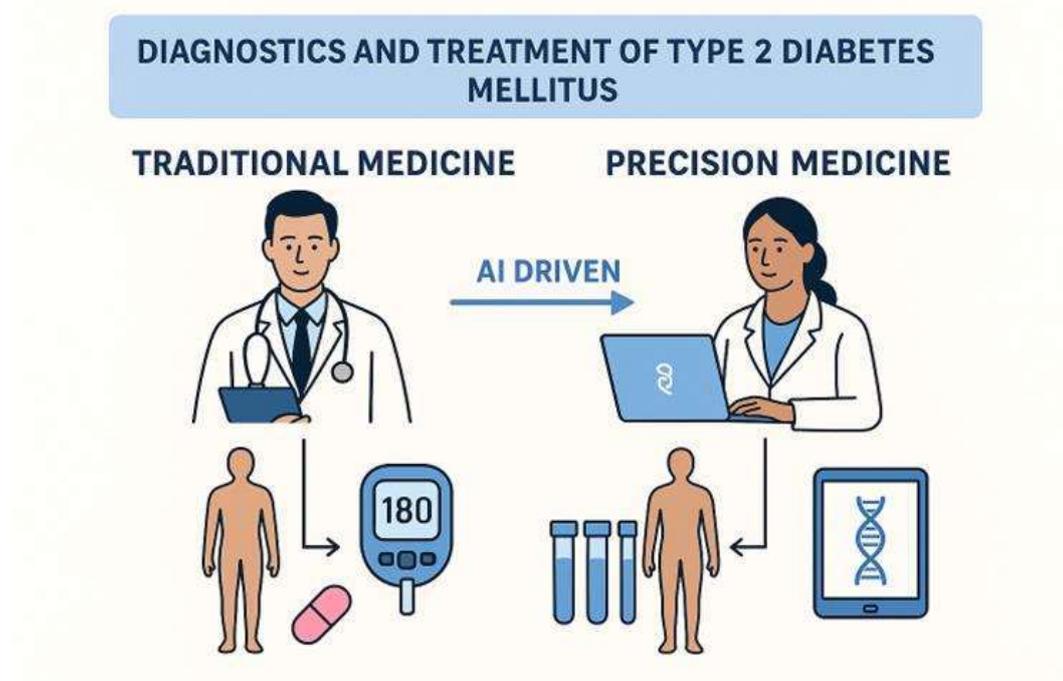


Fig1: Represents comparison between traditional and precision medicine approaches in diagnostics and treatment.

Molecular Docking and Virtual Screening

Molecular docking remains a cornerstone of *in-silico* drug design, enabling prediction of the binding orientation, affinity, and stability of ligands within the active site of a target protein. In T2DM research, docking has been extensively applied to targets such as dipeptidyl peptidase-4 (DPP-4), peroxisome proliferator-activated receptor gamma (PPAR γ), and sodium–glucose cotransporter-2 (SGLT2). High-throughput virtual screening allows thousands of chemical entities—including synthetic libraries and phytochemical databases—to be computationally screened, significantly reducing the cost and time required to identify lead candidates. Advanced scoring functions and ensemble docking further improve accuracy by incorporating protein flexibility and solvent effects.

Pharmacophore Modelling and Quantitative Structure–Activity Relationship (QSAR)

Ligand-based drug design techniques such as pharmacophore modelling identify critical structural and chemical features responsible for biological activity. Pharmacophore models have been developed for DPP-4 inhibitors and AMPK activators, guiding the design of structurally novel yet functionally potent molecules. Complementarily, QSAR modelling correlates chemical descriptors (e.g., hydrophobicity, electronic distribution, molecular geometry) with biological activity, enabling predictive mapping of structure–function relationships. Machine learning–driven QSAR approaches now allow non-linear modelling, enhancing predictive accuracy and applicability for T2DM drug candidates.

Molecular Dynamics (MD) Simulations

While docking provides static snapshots of drug–target interactions, MD simulations offer dynamic insights by modelling atomic-level motions over time. In T2DM research, MD simulations validate docking poses, assess conformational flexibility of proteins (e.g., PPAR γ ligand-binding domain), and explore induced-fit mechanisms critical for drug efficacy. Free-energy calculations, such as MM-PBSA and MM-GBSA, further quantify binding affinities, enabling rational prioritization of lead molecules. With the advent of GPU-accelerated algorithms, MD simulations can now capture micro- to millisecond dynamics, enhancing predictive power in T2DM drug design (13).

Network Pharmacology and Systems Biology

T2DM is inherently polygenic and multifactorial, with interlinked pathways involving glucose metabolism, insulin signaling, lipid homeostasis, and oxidative stress. Network pharmacology integrates omics data with computational modelling to capture these complex interactions. By mapping drug target pathway networks, multitarget therapeutic strategies can be rationalized, particularly for phytochemicals exhibiting pleiotropic activity. For example, network pharmacology has elucidated how plant-derived compounds modulate DPP-4, AMPK, and PI3K–Akt pathways simultaneously, offering synergistic benefits over single-target drugs (14).

Artificial Intelligence and Machine Learning in Drug Discovery

Recent advances in AI and machine learning (ML) have accelerated *in silico* drug design by enabling predictive modelling, generative chemistry, and multi-objective optimization. Deep learning models can predict binding affinities, classify active vs. inactive compounds, and generate novel chemical scaffolds. Reinforcement learning approaches allow AI systems to “design” compounds optimized for activity, selectivity, and ADMET properties. In T2DM research, AI has been applied to identify novel scaffolds for DPP-4 and SGLT2 inhibitors, optimize pharmacokinetics, and even stratify patients for precision therapy using integrated genomic and clinical datasets. AI augments every stage of T2DM care and therapeutics from patient stratification and early diagnosis to drug discovery and closed-loop treatment by converting heterogeneous health data into actionable predictions. A typical AI implementation pipeline for T2DM comprises: (1) data acquisition and harmonization (EHRs, wearables, CGM, imaging, omics), (2) feature engineering and representation (temporal embeddings, multimodal fusion), (3) model development (supervised, unsupervised, reinforcement, generative), (4) model interpretability and safety checks (XAI, bias audits), and (5) clinical/experimental deployment with continuous monitoring and recalibration. AI’s capacity to personalize risk scores, predict complications, and propose therapeutic interventions makes

it a natural fit for T2DM's heterogeneous clinical phenotypes. Clinical adoption requires transparent models and clear evidence of safety/efficacy. Explainable AI (XAI) methods (feature attribution, counterfactuals, concept bottleneck models) provide clinician-interpretable rationales for model outputs and highlight potential failure modes. Regulatory frameworks (FDA/EMA) expect technical documentation, bias/robustness analyses, monitoring plans, and post-market surveillance. AI models for T2DM should be validated on prospective cohorts and randomized-controlled settings where possible.

Discussion

The landscape of type 2 diabetes mellitus (T2DM) management is undergoing a paradigm shift, moving from empirical pharmacology toward precision-driven therapeutics informed by computational and artificial intelligence (AI) frameworks. This review has highlighted the transformative potential of *in silico* methodologies molecular docking, pharmacophore modeling, quantitative structure–activity relationships (QSAR), molecular dynamics (MD) simulations, and network pharmacology complemented by machine learning–driven predictive models. When integrated, these tools collectively accelerate the identification, optimization, and translation of drug candidates while minimizing attrition in the discovery pipeline. From a SMART perspective, the application of *in silico* drug design to T2DM therapeutics can be characterized as follows:

Targeting well-defined molecular drivers of T2DM such as DPP-4, PPAR γ , AMPK, AKR1B1, and SGLT2 ensures that computational pipelines are directed at validated and mechanistically relevant proteins. Natural compounds, including quercetin, mangiferin, jamboline, ursolic acid, and ginsenosides, further exemplify specificity by demonstrating multitarget binding profiles consistent with T2DM's polygenic ethology .

The success of computational strategies can be quantified through docking scores, binding free-energy estimations; pharmacophore fit values, and ADMET predictions. These measurable outcomes provide reproducible metrics that can be benchmarked against experimental assays, ensuring accountability in translational workflows.

Advances in GPU-accelerated computing, cloud-based simulation platforms, and open-source databases make high-fidelity modelling accessible to academic and industrial laboratories alike. This democratization of computational resources renders the large-scale exploration of chemical space practically achievable, even for resource-limited settings.

With the global burden of T2DM escalating, computational approaches offer relevance by directly addressing unmet clinical needs enhancing therapeutic efficacy, reducing side effects, and enabling patient stratification through AI-driven multi-omics integration. Importantly, the relevance of these methods is underscored by their capacity to complement, rather than replace, empirical pharmacology.

In-silico pipelines dramatically reduce the time from target identification to lead optimization. Whereas traditional drug discovery may require a decade or more, AI-augmented modeling and generative chemistry now compress these timelines into months, expediting the delivery of candidate molecules to preclinical testing.

Despite these advances, challenges remain. The accuracy of docking and QSAR models is constrained by the quality of structural and bioactivity data, and most computational hits still require extensive experimental validation. Furthermore, the multitarget nature of phytochemicals, while advantageous, complicates the deconvolution of mechanistic pathways. AI models, although powerful, face limitations related to data heterogeneity, bias, and lack of interpretability. Clinical translation is also hindered by regulatory uncertainties surrounding AI-driven drug design and the absence of standardized validation frameworks.

Nonetheless, the trajectory is clear: the integration of AI, *in silico* modelling, and systems biology is not merely an academic exercise but a pragmatic necessity in the face of T2DM's growing prevalence. Digital twin models, federated learning for multi-institutional data integration and generative molecular design represent the next frontier in therapeutic discovery. These innovations promise to transform T2DM management from a generalized pharmacological approach into a precision-guided discipline that is patient-centric, mechanism-informed, and computationally optimized.

Conclusion

T2DM remains a multifactorial metabolic disorder with a complex pathophysiology that demands innovative therapeutic strategies beyond conventional pharmacology. The integration of AI with *in-silico* drug design has revolutionized the discovery pipeline by enabling rapid, cost-effective, and mechanism-oriented identification of lead molecules. Computational methods such as molecular docking, QSAR modelling, pharmacophore mapping, molecular dynamics simulations, and network pharmacology provide a robust framework to predict drug target interactions, optimize pharmacokinetics, and assess toxicity profiles prior to experimental validation. The incorporation of natural compounds within these pipelines further strengthens drug discovery, as phytochemicals often exhibit multitarget activities that align with the polygenic and multifaceted nature of T2DM.

AI has amplified the predictive power of *in-silico* models by integrating multi-omics data, learning complex disease signatures, and generating novel molecular scaffolds with unprecedented precision. Although challenges persist including data heterogeneity, validation requirements, and regulatory barriers the convergence of AI and computational biology holds immense promise for patient-centric, precision-guided therapeutics.

In conclusion, *In-silico* and AI-based approaches represent not only an adjunct but a transformative paradigm in T2DM drug discovery. Their continued advancement is poised to redefine diabetes management, reduce global disease burden, and usher in a new era of digital-driven precision medicine.

Highlighted the applications for prioritizing T2DM targets including DPP-4, PPAR γ , AKR1B1, HSD11B1, and IDE alongside network pharmacology to rationalize multitarget interventions and phytochemical repurposing. Integrative pipelines that fuse protein structure prediction, ensemble docking, and AI-driven generative chemistry show promise for rapidly exploring chemical space while aligning with medicinal chemistry constraints. Translational considerations assay selection, physiologically based pharmacokinetics, and validation in relevant *in-vitro* and *in-vivo* models are outlined to bridge computational hits to leads.

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An overview on past COVID-19:

Origin, Diagnosis, Treatment, and India's Response

Krishna Kumar Das¹, Santosh Kumar Behera², Suprava Sahoo¹, Basudeba Kar^{1*}

^{1*} Centre for Biotechnology,

Siksha 'O' Anusandhan deemed to be University, Bhubaneswar, Odisha, India-751003

² National Institute of Pharmaceutical Education and Research (NIPER),

Ahmedabad-382355, Gujarat, India.

Abstract

The novel coronavirus, currently referred to by several names such as 2019-nCoV, SARS-CoV-2, and HCoV-19, was classified by the Coronavirus Study Group of the International Committee on Taxonomy of Viruses (ICTV) according to its taxonomic features. The outbreak, which originated in Wuhan, Hubei Province, China, rapidly expanded to affect 199 countries and territories worldwide, instilling widespread fear and disruption comparable to the devastation caused by world wars. Due to the absence of specific vaccines and effective antiviral drugs during the early phase of the pandemic, the World Health Organization (WHO) declared it a Public Health Emergency of International Concern. In light of the virus's rapid human-to-human transmission and the lack of targeted therapeutics, preventive measures and precautionary strategies remain the most effective means of controlling and mitigating the spread of this highly infectious pathogen.

Keywords: Coronavirus, COVID-19, SARS-CoV-2, HCoV-19, Therapeutics, Wuhan.

Introduction

The Wuhan Human 1 coronavirus (WHCV) was named after its initial emergence in Wuhan, Hubei Province, China. In December 2019, numerous cases of severe pneumonia with significant morbidity and mortality were reported among the local population. The infection soon disseminated globally, affecting 199 countries and territories. Consequently, on January 30, 2020, the World Health Organization (WHO) declared the epidemic to be a Public Health Emergency of International Concern (PHEIC). The illness caused by the novel coronavirus was later officially called Coronavirus Disease 2019 (COVID-19) by the WHO on February 12, 2020, and it was classified as a pandemic on March 12, 2020.

Because its origin is unknown, there has been much discussion on the taxonomic classification of this recently discovered coronavirus. A new coronavirus discovered in 2019 was first named 2019-nCoV by the Coronavirus Study Group (CSG) of the International Committee on Taxonomy of Viruses (ICTV). It was subsequently called Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) after phylogenetic analyses showed similarities with the SARS-CoV. Nonetheless, a number of experts contended that the term Human Coronavirus 2019 (HCoV-19) was better in line with the COVID-19 illness nomenclature (Jiang et al., 2020).

The recently discovered HCoV-19 is an enveloped, non-segmented, positive-sense

RNA virus that is a member of the family Coronaviridae, genus Betacoronavirus, and subfamily Orthocoronavirinae. Dry cough, dyspnea, fever, headache, and pneumonia are typical clinical signs throughout the two to fourteen-day incubation period. Severe infections can damage alveoli, resulting in acute respiratory distress and even death (Chan et al., 2020; Chen et al., 2020; Huang et al., 2020).

Members of the Coronaviridae family are widely distributed in mammals, birds, and fish and several are known to cross species barriers, leading to zoonotic transmission. Human infection typically occurs through close person-to-person contact, respiratory droplets, or contaminated surfaces, with viral entry via the mouth, nose, or eyes. Despite having genomic similarities to both SARS-CoV and Middle East Respiratory Syndrome coronavirus (MERS-CoV), SARS-CoV-2 is a unique strain of the virus that can cause anything from mild upper respiratory sickness to severe pneumonia and bronchitis.

Types : Corona viruses Vs. Human Infections

Coronaviruses belong to the subfamily Coronavirinae within the family Coronaviridae. Several types of human coronaviruses (HCoV) have been identified based on the severity and clinical manifestations of the infections they cause. The most commonly recognized human coronaviruses include:

- HCoV-229E (alpha coronavirus)
- HCoV-NL63 (alpha coronavirus)
- HCoV-OC43 (beta coronavirus)
- HCoV-HKU1 (beta coronavirus)

Among these, HCoV-229E was one of the earliest discovered strains, usually linked to common cold-like mild upper respiratory tract infections in healthy people. However, in elderly patients or those with underlying health conditions, it can progress to more severe forms, including lower respiratory tract infections (LRTIs) and acute respiratory distress syndrome (ARDS).

HCoV-NL63, a new human coronavirus, was initially discovered in the Netherlands in 2004 in a seven-month-old baby who had respiratory symptoms. This strain primarily infects children and immune-compromised individuals, causing either mild upper respiratory illnesses such as cough, fever, and rhinorrhea, or, in more severe cases, bronchitis and croup, particularly in young children.

Similarly, HCoV-OC43 was identified in Hong Kong through a molecular characterization study conducted between November 2004 and February 2011, involving 29 patients with acute respiratory tract infections. This strain is known to circulate seasonally and contributes to both upper and lower respiratory diseases.

Infections caused by HCoV-HKU1 are generally mild but can occasionally lead to severe

respiratory complications, including pneumonia, especially in infants, elderly individuals, and immune compromised patients. The HKU1 strain exhibits a unique replication pattern, being able to multiply only in well-differentiated primary human tracheal bronchial epithelial (HTBE) cells and human alveolar type II (hATII) cells.

However, some coronaviruses are notably more virulent than others, such as MERS-CoV, which causes MERS, and SARS-CoV, which causes severe acute respiratory syndrome (SARS). A novel strain of SARS-CoV-2 that first surfaced in Wuhan, China, in late 2019 and swiftly spread throughout the world was the source of the COVID-19 pandemic.

Severe Acute Respiratory Syndrome (SARS)

A severe and frequently fatal form of pneumonia is the main symptom of SARS, an infectious disease caused by the SARS-CoV. The initial outbreak was recorded in November 2002 in Guangdong Province, China, and subsequently spread to Hong Kong before reaching over 24 countries worldwide.

The virus targets both the upper and lower respiratory tracts, leading to a spectrum of clinical manifestations. During the early stages of infection, patients typically present with flu-like symptoms, including dry cough, chills, fever, diarrhea, shortness of breath, and myalgia. As the disease advances, pneumonia commonly develops, and in severe cases, complications such as respiratory failure, cardiac dysfunction, and hepatic impairment may occur.

According to data from the Centers for Disease Control and Prevention (CDC), the global SARS outbreak affected 8,098 individuals, resulting in 774 deaths, corresponding to a case fatality rate of approximately 9.6%.

Middle East Respiratory Syndrome (MERS)

MERS is a viral disease caused by the MERS-CoV, which was first identified in Saudi Arabia in 2012. Following its discovery, the infection was reported in multiple countries across the Middle East, Europe, Asia, and North America, primarily linked to travel or contact with infected individuals.

The clinical presentation of MERS often involves fever, cough, and shortness of breath, however some individuals may also develop gastrointestinal symptoms such as diarrhoea or nausea. Close contact with infected patients is the primary method of human-to-human transmission, especially in healthcare settings.

According to epidemiological data published in 2019, MERS exhibited a case fatality rate of approximately 35.2%, categorizing it among the most severe coronavirus infections known prior to the COVID-19 pandemic.

COVID-19

December 2019, cases of pneumonia with unknown sources were reported in Wuhan,

Hubei Province, China. A new coronavirus was shown to be the causal culprit in later studies. In early 2020, the WHO formally recognized this virus as SARS-CoV-2 and termed the accompanying sickness COVID-19.

This newly emerged viral strain rapidly spread worldwide, resulting in a global pandemic characterized by significant morbidity and mortality across diverse populations.

Symptoms of Covid-19 Infection

COVID-19 has the sign and symptoms which appear within 2-14 days. All the symptoms are appearing in every stage of infection. In the juvenile stage some basic symptoms are identified but day after day past the infection and the symptoms are get rigid and harmful to health. The major symptoms include fever, cough, runny nose, aches, shortness of breath, tiredness, sore throat which are shown in **fig.1**:

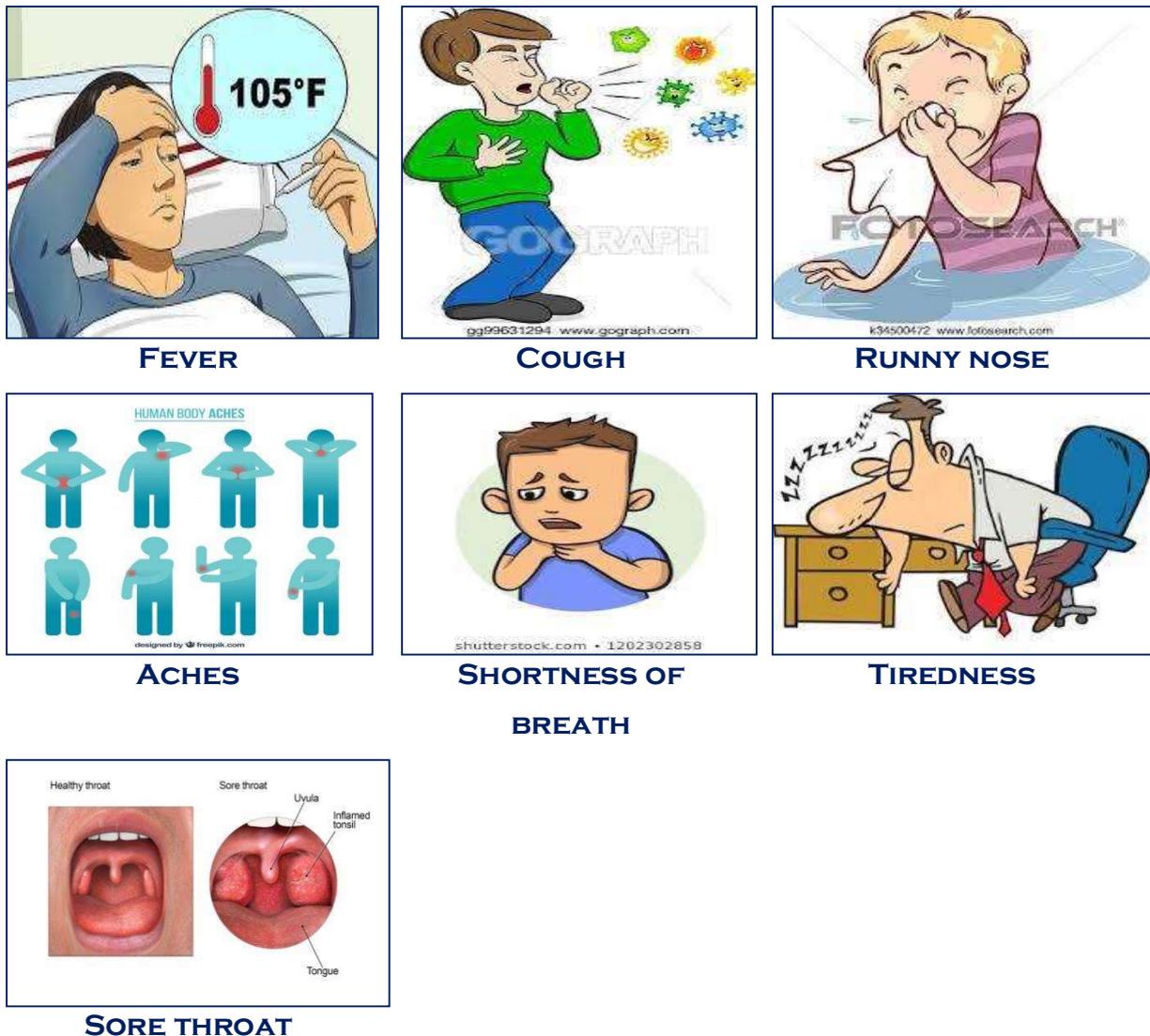


Fig.1: Sign and symptoms of COVID-19

After contracting COVID-19, people who are older or have pre-existing chronic diseases including diabetes, cardiovascular disease, or respiratory disorders are more likely to

experience serious complications. Beyond the common symptoms, several serious health complications have been documented, including:

- Pneumonia affecting both lungs
- Multiple organ failure involving vital organs
- Death in critical cases

Prevention from Infection

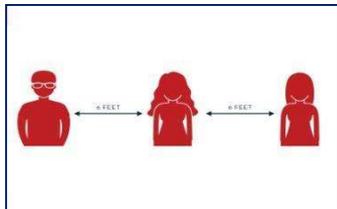
Till date there is hardly any vaccine or potential antiviral drug for COVID-19 therapeutics. Precautionary measures are to be followed for reducing the risk of infection. WHO and CDC recommended the following below steps of prevention for avoiding COVID-19. They are shown in the **fig.2:**



Stay Away from Crowds.



Maintain Safe Distance



Distance to Prevent Spread.



Use Soap or Sanitizer



Cover Coughs and Sneezes



Prevent Hand-to-Face Contact



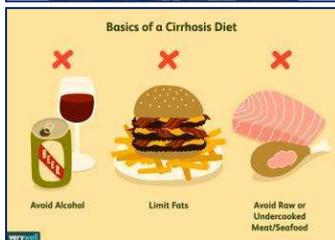
No Sharing While Sick



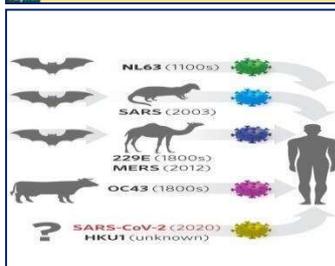
Disinfect Frequently Touched Areas



Home Isolation During Illness



Avoid Raw Animal Products



Limit Animal Interaction

Fig.2: Steps of prevention for avoiding COVID-19

Laboratory Diagnosis and Findings

Detection and Sampling Methods for Human Coronaviruses (HCoVs)

Numerous upper and lower respiratory tract specimens, such as throat, nasal, and nasopharyngeal (NP) swabs, as well as sputum and bronchial secretions, have been found to contain endemic human coronaviruses (HCoVs). According to Wang et al., oropharyngeal (OP) swabs (n = 398) were more commonly utilized in China during the COVID-19 outbreak than nasopharyngeal (NP) swabs (n = 8). However, compared to the 63% positive found in NP swabs, the detection percentage of SARS-CoV-2 RNA in OP swabs was just 32%.

The U.S. Centers for Disease Control and Prevention (CDC) recommended NP swabs as the preferred specimen type for upper respiratory sampling. OP swabs were considered secondary and, if collected, were advised to be combined with NP specimens in a single transport medium. It was advised to maintain all swab samples in a viral or universal transport medium. Aspirates from the nasopharynx were also found to be appropriate for HCoV detection.

Concurrent testing of upper and lower respiratory tract specimens, such as sputum and bronchoalveolar lavage (BAL) fluid, was recommended for the best diagnostic sensitivity in identifying SARS-CoV, MERS-CoV, and SARS-CoV-2. However, procedures such as sputum induction and bronchoscopy posed substantial biosafety risks due to the potential for aerosol generation, necessitating the use of appropriate personal protective equipment (PPE) by healthcare personnel. Because bronchoscopy requires trained professionals and specialized facilities, it was not widely accessible in all clinical settings.

Beyond respiratory samples, SARS-CoV and MERS-CoV RNA were also identified in stool, urine, and blood specimens, though these sample types were generally considered less reliable for diagnostic purposes. For maximum sensitivity, upper respiratory tract samples were best collected during the early phase of infection, typically within the first few days of symptom onset, while RNA concentrations in lower respiratory tract samples often peaked during the second and third weeks of illness.

For SARS-CoV, a similar trend was seen, with lower respiratory specimens remaining positive for up to three weeks and upper respiratory sample RNA positivity rates peaking between seven and ten days after the onset of symptoms. Furthermore, a study discovered that respiratory samples from people with diabetes mellitus showed prolonged MERS-CoV RNA shedding.

Since viral pneumonias rarely produce purulent sputum, nasopharyngeal swabs or washes are generally preferred for diagnostic sampling. However, in some early infections, NP swabs may fail to detect the virus, necessitating deeper specimen collection via bronchoscopy.

Notably, self-collected saliva specimens tested positive for SARS-CoV-2 RNA in 11 of 12 COVID-19 patients, highlighting their potential as a non-invasive diagnostic alternative. For laboratory storage, specimens intended for HCoV testing should be kept at 2–8°C for up to 72 hours, or frozen at –70°C or below for longer preservation. Furthermore, rectal samples have also tested positive for SARS-CoV-2 RNA, suggesting a possible gastrointestinal route of infection in certain cases.

Rapid antigen tests

Diao et al. showed in a pre-peer-reviewed study that a fluorescence immunochromatographic assay was a precise, quick, and easy diagnostic technique for the early identification of the SARS-CoV-2 nucleocapsid (N) protein in nasopharyngeal (NP) swab samples. This method demonstrated a great deal of promise for promoting early COVID-19 detection. To improve the sensitivity of quick antigen tests used for respiratory viral infections, the use of colloidal gold-labelled immunoglobulin G (IgG) as a detection reagent

was also suggested.

At the same time, monoclonal antibodies specifically designed to recognize SARS-CoV-2 antigens were under development to improve diagnostic accuracy. In parallel, Sona Nanotech Inc. (Halifax, Canada) was working on the creation of a rapid-response lateral flow assay intended for COVID-19 screening. The test was designed to provide results within 5 to 15 minutes, offering a valuable point-of-care diagnostic tool to support timely clinical decision-making and large-scale population screening during the pandemic.

Serology

Serological assays play a crucial role in understanding the epidemiological dynamics of emerging human coronaviruses (HCoVs), including their infection burden and the contribution of asymptomatic carriers. These assays are particularly valuable for antibody-based detection in diagnosing infections caused by novel and re-emerging coronaviruses, such as SARS-CoV and MERS-CoV.

Following the identification of SARS-CoV-2, serological testing became an important complementary diagnostic approach, especially in settings where molecular or rapid antigen tests were either unavailable or unreliable. Recent research revealed that patients infected with SARS-CoV-2 could have IgM and IgG antibodies as early as five days after the onset of symptoms.

In response to the urgent diagnostic demand, China's National Medical Products Administration (NMPA) granted emergency approval to six serological testing kits by March 12, 2020, enabling broader screening and epidemiological surveillance during the early stages of the COVID-19 pandemic.

Detection of SARS-CoV-2 Using RT-PCR Assays

Nasopharyngeal swabs or sputum specimens collected from patients were analyzed using real-time reverse transcription polymerase chain reaction (RT-PCR) assays targeting the highly conserved RNA-dependent RNA polymerase (RdRp) and variable spike (S) genes of SARS-CoV-2. The cycle threshold (Ct) values for sputum samples were found to be 8–13 cycles lower than those for throat swabs, suggesting a higher viral load in the lower respiratory tract. This observation aligns with findings from MERS-CoV infections, where elevated viral titers were also noted in lower respiratory specimens compared to upper tract samples.

Serum testing occasionally detected viral RNA, indicating potential viral dissemination from severely infected pulmonary tissues into systemic circulation. However, in the first reported U.S. COVID-19 case, both respiratory and stool specimens tested positive for SARS-CoV-2 RNA by RT-PCR, while serum samples remained negative. Notably, chest computed

tomography (CT) scans showing ground-glass opacities sometimes revealed abnormalities earlier than positive RT-PCR results, emphasizing the diagnostic value of imaging. In order to guarantee an accurate diagnosis and prompt action, repeated RT-PCR testing of nasopharyngeal or sputum samples is advised in clinically suspected patients with initially negative results.

Treatment

Medicines for clinical treatment

At present, no specific antiviral drug or universally approved vaccine has been confirmed to be fully safe and effective against COVID-19. Management of the disease primarily relies on supportive care, including oxygen supplementation, adequate hydration, antipyretic and analgesic therapy, and the use of antibiotics in cases of confirmed bacterial co-infection.

Several antiviral agents have been explored for their potential efficacy, such as α -interferon (administered via aerosol inhalation), lopinavir/ritonavir, ribavirin, chloroquine phosphate, and umifenovir. In cases of severe pulmonary involvement or patients exhibiting elevated interleukin-6 (IL-6) levels, tocilizumab, an IL-6 receptor antagonist, has been suggested as an immunotherapeutic option. However, the concurrent use of three or more antiviral drugs is not recommended due to the increased risk of adverse interactions. Comparative evaluations between dual combinations (recombinant interferon α -2b + lopinavir/ritonavir) and triple combinations (umifenovir + recombinant interferon α -2b + lopinavir/ritonavir) have been conducted to assess antiviral efficacy.

For individuals with mild infection, home isolation and symptomatic management are generally sufficient. Nonetheless, elderly patients (over 65–70 years, depending on national guidelines) and those with underlying health conditions such as cardiovascular disease, diabetes, chronic respiratory disorders, malignancies, or immunodeficiency are advised to seek closer medical supervision due to their higher risk of developing severe complications. Paracetamol (acetaminophen) remains a commonly recommended option for fever control in COVID-19 patients.

During the course of the COVID-19 pandemic, multiple vaccines were developed and administered globally. Their primary goal has been to reduce the severity of illness, hospitalizations, and mortality associated with SARS-CoV-2 infection, thereby providing an essential tool in controlling the pandemic's global impact.

Table.1 showing the vaccine used during the pandemic period of COVID

Vaccine Name		Type	Main Uses
Pfizer-BioNTech (Comirnaty)		mRNA	Prevention of COVID-19 in ages 6 months and older; high efficacy, rapid response to new variants
Moderna (Spikevax, Mnexspike)		mRNA	Prevention of COVID-19, used for ages 6 months+ and high-risk groups; strong immunogenic response
Novavax (Nuvaxovid)		Protein subunit	Alternative for those unable to take mRNA vaccines, approved for ages 12+ and elderly; key for new variant protection
AstraZeneca (Vaxzevria/Covishield)		Viral vector	Widely used in adults; cost-effective, important for global distribution
Johnson & Johnson (Jcovden)		Viral vector	Single-dose regimen for adults, useful for rapid large-scale immunization
Sinopharm/Sinovac		Inactivated virus	Used primarily in Asia and South America; easy storage, regional coverage
Covaxin		Inactivated virus	Developed in India; used to reduce disease severity and transmission in adults
Covovax		Protein subunit	Novavax formulation available in India; alternative for specific populations
Sputnik V		Viral vector	Developed in Russia; approved in many countries for adults
ZyCoV-D	DNA vaccine	First DNA-based COVID-19 vaccine, developed in India	



Fig.3: Most Important vaccination during COVID-19

Uses and Benefits

The global deployment of COVID-19 vaccines significantly contributed to mitigating the severity of disease, reducing hospital admissions, and preventing mortality, particularly among high-risk groups such as healthcare professionals, elderly individuals, patients with chronic illnesses, and those with compromised immune systems. Vaccines based on mRNA platforms, including Pfizer–BioNTech and Moderna, were rapidly modified to address emerging SARS-CoV-2 variants, ensuring continued effectiveness against evolving strains. In addition, protein subunit vaccines such as Novavax offered alternative immunization options for individuals unable to receive mRNA-based vaccines or those preferring non-mRNA formulations. The implementation of mass immunization campaigns across countries proved instrumental in controlling viral transmission, facilitating safer reopening of societies, and reducing the overall public health burden. Collectively, COVID-19 vaccination programs have played a pivotal role in pandemic control, and ongoing efforts to update vaccine formulations remain vital in combating new variants and preventing future infection surges.

Convalescent Plasma Therapy (CPT) in COVID-19 Management

Convalescent plasma therapy (CPT) involves the transfusion of plasma containing a defined titer of virus-specific neutralizing antibodies from recovered individuals to patients currently battling infection. This therapeutic approach aims to provide passive immunity, facilitating the neutralization and clearance of circulating viral particles. Historically, CPT has demonstrated efficacy in the management of Severe Acute Respiratory Syndrome (SARS) and H1N1 influenza, establishing it as a promising adjunctive treatment strategy for emerging viral diseases. The administration of CPT is generally guided by specific clinical criteria. Ideally, the disease course should be within three weeks of onset, and patients must have confirmed viraemia or a positive viral nucleic acid test, verified by qualified clinical experts. CPT is particularly considered for severe or critically ill patients, especially during the early stages of disease progression, or for those identified by multidisciplinary clinical assessment as requiring plasma therapy. The recommended dosage typically ranges from 200 to 500 mL (approximately 4–5 mL/kg body weight), adjusted according to the patient's clinical status and tolerance. While CPT is generally well tolerated, several transfusion-related adverse reactions have been reported. These may include transfusion-associated circulatory overload (TACO), transfusion-related acute lung injury (TRALI), dyspnoea, allergic and hypotensive reactions, non-haemolytic febrile responses, acute or delayed haemolytic reactions, and, in rare cases, infectious or idiopathic transfusion complications. Therefore, close clinical monitoring and appropriate donor screening are essential to ensure the safety and efficacy of CPT administration.

Clinical trials for the treatment of COVID-19

A diverse range of pharmacological and therapeutic agents have been evaluated in clinical trials for the management of COVID-19. These include Traditional Chinese Medicine (TCM) formulations (approximately 64 trials), antiviral agents (40 trials), and immunotherapeutic drugs (28 trials), such as interferons, thymosin, immunoglobulins, and PD-1 inhibitors. Additionally, anti-malarial agents like chloroquine, hydroxychloroquine, and chloroquine phosphate have been investigated in 21 studies, while glucocorticoids were assessed in six clinical evaluations. Other pharmacological compounds (22 trials) have explored the roles of vitamin C, vitamin D, polymyxin injections, zinc sulfate, and acetylcysteine, among others. Among antiviral agents, anti-HIV drugs such as lopinavir/ritonavir, darunavir/cobicistat, and azvudine represented the most frequently studied category (14 trials). This was followed by anti-influenza agents (13 trials) including umifenovir and favipiravir, both of which demonstrated potential antiviral activity against SARS-CoV-2. Notably, remdesivir was the subject of five separate clinical investigations, given its broad-spectrum antiviral properties and potential efficacy against COVID-19.

COVID-19 Outbreak and Response in India

In India, the spread of COVID-19 progressed at a relatively slower rate compared to several developed nations, likely due to early government interventions and strong public health measures. The Government of India implemented multiple laws, regulations, and awareness programs to mitigate transmission. On 22 March 2020, the nation observed a 14-hour voluntary public curfew (Janata Curfew), followed by a 21-day nationwide lockdown to contain the spread of the virus. By 20 May 2020, India had recorded 1,06,468 confirmed cases, including 42,307 recoveries and 3,301 deaths, with Maharashtra, Tamil Nadu, Gujarat, and Delhi reporting the highest case counts. To manage the escalating situation, the government invoked the Epidemic Diseases Act of 1897, empowering authorities to impose strict restrictions under Section 188 of the Indian Penal Code (IPC).

The Indian Council of Medical Research (ICMR) utilized epidemiological modeling to project case scenarios and highlight the importance of testing and isolation. By that period, ICMR had scaled up testing capacity to 10,000 tests per day, operating through 111 government and 60 private laboratories. In Odisha, the Regional Medical Research Centre (RMRC), Bhubaneswar was designated as a COVID-19 testing facility, equipped with the required infrastructure for viral diagnostics once adequate testing kits became available.

Conclusion

Government of India is taking all necessary steps to make sure that it has a tendency to square measure, and ready to face the challenges and threat exposed by the growing pandemic of COVID-19 infection. With active support of all the individuals worldwide through following the DO's and Don'ts, we could pack-up the deadliest virus. The foremost necessary think about preventing the spread of the virus domestically is to empower the citizens with the correct data and taking precautions as per the advisories being issued by Ministry of Health & Family Welfare of respective countries of the world.

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Web Links for getting latest updates on COVID-2019

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2. <https://www.cebm.net/global-covid-19-case-fatality-rates/>
3. www.covid19india.org

Gamification in Education: An Intangible Approach

Author- Srikshetradas Panda

Department of Computer Science

Indian Institute of Management and Science, Palaspur, Bhubaneswar

Abstract

Gamification in education has appeared as a ground-breaking pedagogical approach that assimilates game design elements into non-game learning environments to enhance motivation, engagement, and knowledge preservation. This conceptual paper explores the theoretical foundations, principles, and applications of gamification in modern educational contexts. Drawing on awareness from behavioral psychology, self-determination theory, and progressive learning models, the study highlights how elements such as points, badges, leader boards, and challenges fuel essential and superficial motivation among learners. Gamification links the gap between entertainment and education by converting passive learning into an active, goal-oriented experience. It boosts collaboration, problem-solving, and creativity while promoting personalized learning corridors. The paper also scrutinizes various digital tools and platforms that have combined gamified elements into classroom and e-learning systems, demonstrating their potential in cultivating academic outcomes and learner satisfaction. Despite its advantages, gamification faces experiments including superficial implementation, overemphasis on competition, and varying learner fondness. Therefore, successful gamification needs a balance between playfulness and pedagogy, line up educational goals with engaging experiences. This study concludes that gamification, when applied thoughtfully and ethically, holds significant potential to redefine learning patterns in the 21st century by nurturing sustained motivation, engagement, and learner autonomy across diverse educational settings.

Keywords

Gamification, Education Technology, Motivation, Learning Theories, Pedagogy, Game Design, Engagement

1. Introduction

Education in the 21st century is undergoing a pattern shift driven by technological advancement, learner variety, and the need for shared learning experiences. Traditional teacher-centered models are gradually being replaced by learner-centered methods that lay emphasis on active participation and personalized learning. In this context, *gamification*—the application of game mechanics in non-gaming environments—has developed as one of the most influential innovations in educational design.

Gamification does not mean turning education into a video game. Instead, it involves adding elements such as points, badges, leader boards, progress bars, challenges, and feedback systems into learning processes to increase motivation, focus, and participation. When

learners receive instant feedback and are rewarded for progress, they tend to keep on longer, act as a team more effectively, and enjoy learning experiences.

Research shows that the human brain is naturally receptive to rewards and challenges. This cognitive principle, when aligned with educational goals, converts gamification into a tool for maintainable engagement. The idea that learning can be pleasant is not new; however, the digital age has permitted educators to operationalize this concept through structured frameworks and learning platforms. Gamification thus represents a fusion of technology, psychology, and pedagogy—making it a vital method for modern educational design.

2. Theoretical Background of Gamification

Gamification as an educational strategy draws upon several theoretical frameworks from psychology, education, and human-computer interaction that explain how and why game-based principles can improve learning engagement and motivation. Its theoretical foundation is not limited to the use of technology but spreads to understanding the psychological processes that impact human behavior and learning outcomes. This section explores key theories that support gamification: Self-Determination Theory, Behaviorism, Constructivism, Flow Theory, and Social Learning Theory.

2.1 Self-Determination Theory (SDT)

Developed by Edward Deci and Richard Ryan (1985), Self-Determination Theory is central to understanding gamification's motivational power. SDT suggests that human motivation is driven by the fulfillment of three fundamental needs: autonomy, competence, and relatedness.

Gamified systems effectively support these needs.

- **Autonomy:** Players (or learners) feel vested to make choices, discover, and take possession of their learning.
- **Competence:** Levels, badges, and feedback provide quantifiable progress, look after a sense of mastery.
- **Relatedness:** Leader boards, teams, and social interactions build connection and teamwork among learners.

By filling these psychological prerequisites, gamification improves fundamental motivation—the internal drive to learn for personal contentment rather than external rewards.

2.2 Behaviorism and Reinforcement Learning

Gamification's reward systems are also deeply influenced by Behaviorists theories, particularly those proposed by B.F. Skinner (1938). Behaviorism highlights noticeable actions and the role of support in shaping behavior. Points, rewards, and immediate feedback in

gamified environments act as positive reinforcements, boosting recurrence of desired learning behaviors. For example, when a learner earns a badge for completing a module, the sense of success motivates continued involvement. This method line up with the operant conditioning structure where behavior is shaped and maintained through methodical rewards and feedback.

2.3 Constructivism and Experiential Learning

Experiential theorists like Jean Piaget and Lev Vygotsky claim that learners construct knowledge actively through experiences and interactions with their environment. Gamification provides specifically this—an interactive and taking part learning setting. In gamified classrooms or e-learning platforms, students engage in problem-solving, experimentation, and reflection, similar to how players engage in games to achieve objectives. Furthermore, Vygotsky’s concept of the Zone of Proximal Development (ZPD) supports with gamification’s use of progressive challenges: tasks are designed to be slightly beyond the learner’s current ability but attainable with guidance or peer cooperation. This platform effect ensures continuous learning growth.

2.4 Flow Theory

Mihaly Csikszentmihalyi’s Flow Theory (1990) describes a psychological state of deep concentration and involvement where individuals are fully engaged in an activity. Gamified environments aim to trigger this “flow state” by balancing challenge and skill. If the challenge is too easy, learners lose interest; if too difficult, they feel upset. Gamification’s use of adaptive difficulty, instant feedback, and progress indicators helps maintain this balance, keeping learners “in the zone.” Flow experiences enhance focus, satisfaction, and long-term learning retention, making it one of the most quoted theoretical foundations in gamified education research.

2.5 Social Learning Theory

Proposed by Albert Bandura (1977), Social Learning Theory lay emphasis on that people learn from noticing others and through social interactions. Gamification influences this concept through collaborative tasks, team challenges, and peer recognition systems. For instance, when learners see peers attaining high scores or cracking badges, it fuels motivation through social reinforcement and observational learning. The sense of community and friendly competition boosts engagement while adopting teamwork and communication skills.

2.6 Cognitive Evaluation and Motivation

In addition to these foundational theories, Cognitive Evaluation Theory (CET)—a sub-theory of SDT—explains how external rewards can either improve or weaken inherent motivation. If rewards (like points or badges) are perceived as controlling, motivation may

decline; but if they are seen as informational and brooding of ability, motivation increases. Therefore, operational gamification must be meaningful and autonomy-supportive, not just reward-driven.

2.7 Integrative Perspective

The theoretical background of gamification shows that it is multidimensional—combining psychological, pedagogical, and technological perceptions. It borrows the motivational mechanisms of games and combines them with educational objectives. By integrating SDT's motivation framework, Behaviorism's support, experiential approach, Flow Theory's engagement principles, and Social Learning Theory's collaborative dimension, gamification offers a holistic educational model. It is not a insincere trend but a echo of deep-rooted learning principles that can transform traditional teaching into dynamic, learner-centered experiences.

3. Principles and Elements of Gamification

Gamification is not just the addition of games into educational settings; it is a systematic design approach that combines core principles and elements of game mechanics into the learning environment to enhance motivation, engagement, and achievement. Understanding these principles is essential to designing effective gamified experiences that align with pedagogical objectives.

3.1 Core Principles of Gamification in Education

1. Motivation and Engagement:

The primary principle of gamification is to stimulate inherent and external motivation. Learners are encouraged to participate in activities through a combination of rewards, feedback, and goal-oriented challenges. Inherent motivation arises from the enjoyment and satisfaction of learning, whereas external motivation is influenced by concrete rewards such as points or badges. A successful gamified system balances both forms, certifying that learners remain busy while developing mastery over content.

2. Goal Orientation:

Gamification laid emphasis on clear objectives and measurable progress. By breaking down learning into smaller attainable goals, learners can experience regular successes, adopting determination and self-efficacy. Goal-oriented design makes sure that learners are conscious of what they are working toward and can monitor their progress, thereby improving responsibility and focus.

3. Feedback and Reflection:

Immediate and actionable feedback is a foundation of gamification. Learners get guidance on performance, allowing them to reflect on errors and improve outcomes. Feedback can be assessable (e.g., points, scores) or qualitative (e.g., narrative comments, suggestions), but it should be sensible and expressive, supporting the learner's sense of ability.

4. Challenge and Skill Balance:

Effective gamification combines challenges that are appropriately matched to the learner's skill level. According to Csikszentmihalyi's Flow Theory, tasks should be neither too easy (which leads to tediousness) nor too difficult (which leads to nervousness). Adaptive gamification adjusts the trouble dynamically, make sure learners remain in a state of flow that maximizes engagement and learning.

5. Social Interaction:

Social elements such as collaboration, competition, and recognition are integral to gamification. Learners are motivated not only by personal achievements but also by peer impact, teamwork, and social assessment. Leader boards, team hunts, and shared challenges influence social dynamics to raise your spirits active participation and community building.

3.2 Key Elements of Gamification

Gamification consists of several interconnected elements that convert ordinary learning activities into engaging experiences:

1. Points and Scoring Systems:

Points calculate learner performance and deliver immediate feedback. They create assessable progress and allow learners to track their successes over time. Points also act as reinforcers, encouraging recurrence of desirable learning behaviors.

2. Badges and Achievements:

Badges represent mastery, happenings, or milestones achieved within the learning process. They serve as exact markers of progress and recognition, increasing motivation and confidence. Badges can be given for completing assignments, mastering skills, or contributing to discussions.

3. Leaderboards and Rankings:

Leaderboards introduce friendly competition, showcasing top performers and nurturing engagement through social evaluation. They encourage learners to try for progress, but careful design is necessary to avoid demotivation among lower-ranking participants.

4. **Levels and Progression:**

Structuring content into levels allows learners to progress gradually, mastering basic concepts before proceeding to complex topics. Progression systems provide clear paths and inspire continuous participation.

5. **Challenges and Quests:**

Challenges change learning activities into goal-oriented tasks or missions. Hunts may be individual or combined and often require problem-solving, critical thinking, and creativity. They deliver purpose and importance to the learning experience.

6. **Feedback Loops:**

Feedback twists are tools that provide continuous information about learner performance. They highlight positive behaviors, correct mistakes, and guide learners toward preferred outcomes. Gamification influences both instant feedback (e.g., quiz results) and shared feedback (e.g., level completion summaries).

7. **Narrative and Storytelling:**

Incorporating a description or story creates an immersive context, connecting tasks and learning objectives in a meaningful way. Storytelling improves engagement by providing sensitive and intellectual investment, making learning unforgettable and relevant.

8. **Rewards and Incentives:**

Physical or immaterial rewards inspire learners to continue engagement. Examples include virtual coins, bonus points, access to exclusive content, or public recognition. Operational rewards are meaningful and aligned with learning goals to avoid supporting external drive at the expense of basic engagement.

3.3 Design Considerations

While these principles and elements are foundational, operative gamification requires attentive integration:

- **Alignment with Learning Objectives:** Gamification should support curriculum goals rather than being an apparent addition.
- **Balance of Competition and Collaboration:** Overemphasis on competition can discourage learners; social and cooperative elements must be highlighted.
- **Inclusivity and Accessibility:** Gamified designs should supply to various learning styles, cultural contexts, and technological access.
- **Sustainability:** Elements like points and badges should not lose importance over time; challenges should go forward to maintain engagement.

4. Application of Gamification in Education

The application of gamification in education extends various contexts, from traditional classrooms to online learning platforms and corporate training environments. Its extensive adoption reflects the appreciation that game elements—when applied thoughtfully—can enhance engagement, motivation, and learning outcomes across age groups and educational levels. This section explores how gamification is implemented in different educational settings, emphasizing practical examples and theoretical suggestions.

4.1 Classroom Integration

In traditional classroom settings, gamification is often used to stimulate participation and support learning concepts. Teachers combine elements such as quizzes, interactive competitions, badges, and progress pursuers to make lessons more engaging. Platforms like Kahoot!, Quizizz, and Classcraft allow educators to gamify assessments, offering instant feedback, points, and ranking systems that inspire students to dynamically participate.

For example, in a mathematics classroom, a teacher might design a point-based system where students earn rewards for solving problems correctly, completing homework on time, or collaborating in group activities. Badges may be awarded for consistent effort, creativity, or mastery of specific concepts. By providing immediate feedback and recognition, gamification transforms otherwise routine learning activities into stimulating challenges that reinforce knowledge retention and classroom engagement.

Additionally, narrative elements and storytelling can be integrated into lessons to contextualize learning. For instance, history teachers might structure units as missions where students “travel” through historical periods, complete tasks, and unlock achievements as they master concepts. This approach promotes lively learning, making mental content more relatable and memorable.

4.2 E-Learning and MOOCs

The rise of online education has significantly expanded the scope of gamification. E-learning platforms and Massive Open Online Courses (MOOCs) face challenges such as learner isolation, low engagement, and high dropout rates. Gamification addresses these issues by providing interactive, goal-oriented experiences.

Applications like Duolingo utilize gamified features such as streaks, level progression, points, and badges to motivate language learners. Progress bars visually represent advancement, while weekly challenges and social leaderboards foster a sense of accountability and friendly competition. Similarly, Coursera, EdX, and other MOOCs integrate gamified quizzes, completion certificates, and peer interaction to enhance learner engagement.

Gamification in e-learning also supports self-paced, personalized learning. Adaptive systems adjust difficulty based on learner performance, maintaining optimal challenge levels and flow. Additionally, rewards and badges can motivate consistent participation, which is critical in self-directed online environments.

4.3 Higher Education

In higher education, gamification is employed to improve understanding of difficult subjects and professional skills. Universities use gamified simulations, virtual labs, and scenario-based exercises to nurture observed learning. For instance, engineering students may take part in virtual projects that reward teamwork, problem-solving, and creative application of speculative knowledge. Medical and nursing programs often hire gamified models to duplicate patient care scenarios, allowing learners to drill decision-making and critical thinking in a safe, risk-free environment.

Gamification also boosts student motivation in courses usually perceived as stimulating or less engaging. By structuring content into levels, providing real-time opinion, and awarding recognition for achievements, instructors can transform learning into an interactive, rewarding experience. Furthermore, peer recognition and cooperative hunts build social learning communities, which are critical for higher-order mental development.

4.4 Corporate and Professional Training

Beyond formal education, gamification has found an important role in corporate training and professional development. Organizations influence gamified systems to improve employee engagement, facilitate onboarding, and promote skill acquisition. Learning management systems (LMS) such as SAP SuccessFactors, Skillsoft, and Axonify integrate points, badges, leaderboards, and scenario-based challenges to boost training effectiveness.

Gamification in corporate settings supports adult learning principles, acknowledging that employees are inspired by practical application, achievement, and self-sufficiency. For example, sales teams might participate in point-based tasks to complete training modules, while customer service staff involve in scenario-based games to enhance problem-solving skills. By providing immediate feedback and real rewards, gamification confirms that learning is both effective and enjoyable.

4.5 Multimodal and Hybrid Learning

The flexibility of gamification enables its assimilation into hybrid and multimodal learning environments, where old-fashioned face-to-face instruction is combined with digital platforms. Gamified mobile applications, interactive e-books, and online combined platforms allow learners to continue engagement outside the classroom. Students can get badges for participating in discussion forums, completing online quizzes, or submitting projects digitally, creating a continuous learning experience across multiple modes.

4.6 Theoretical Implications

The practical applications of gamification in education bring into line with several learning theories discussed earlier:

- **Constructivism:** Students actively construct knowledge through gamified tasks and problem-solving activities.
- **Self-Determination Theory:** Gamification fulfills independence, capability, and understanding needs.
- **Flow Theory:** Adaptive challenges maintain commitment and deep focus.
- **Social Learning Theory:** Collaborative and reasonable features encourage learning through noble interaction.

5. Educational Models and Learning Theories

The effectiveness of gamification in education is deeply rooted in its alignment with established educational models and learning theories. By assimilating game mechanics with educational principles, gamification facilitates active learning, critical thinking, collaboration, and learner autonomy. This section examines key educational frameworks and learning theories that inform gamified instructional design.

5.1 Experiential Learning (Kolb)

David Kolb's Experiential Learning Theory (ELT) posits that learning is a process whereby knowledge is created through experience, reflection, conceptualization, and experimentation. Gamification supports naturally with this model:

1. **Concrete Experience:** Gamified activities provide interactive experiences, such as simulations, role-playing, or virtual labs, allowing learners to keenly engage with content.
2. **Reflective Observation:** Learners receive feedback through points, badges, and progress indicators, encouraging consideration on their performance and decisions.
3. **Abstract Conceptualization:** Learners analyze results, recognize patterns, and connect experiential activities to theoretical concepts.
4. **Active Experimentation:** Gamification inspires learners to test new strategies, solve challenges, and iterate their approaches to achieve objectives.

For example, in a science classroom, students may use a gamified model to experiment with chemical reactions. The system provides instant feedback, enabling learners to reflect and adjust their approach, effectively closing the observed learning twist.

5.2 Problem-Based Learning (PBL)

Problem-Based Learning give emphasis to learning through the exploration of real-world problems. Gamification boosts PBL by structuring challenges as quests or works that

require investigation, critical thinking, and collaboration. Tasks are designed to be progressively challenging, with rewards and recognition inspiring diligence.

In engineering education, students may be tasked with planning a supportable energy solution within a gamified environment. Points and badges are awarded for research, teamwork, and inventive solutions, making the problem-solving process engaging, goal-oriented, and interactive.

5.3 Collaborative and Social Learning

Social interaction is central to both Vygotsky's Social Interactionist Theory and Bandura's Social Learning Theory. Gamification fosters collaboration and peer learning through:

- Team-based quests or missions
- Leaderboards and rankings boosting collective attainment
- Discussion forums integrated with points or badges for assistances

5.4 Bloom's Taxonomy and Cognitive Development

Gamification can be represented to **Bloom's Taxonomy**, addressing various mental levels:

- **Remembering:** Quick quizzes and flashcards with point rewards strengthen realistic knowledge.
- **Understanding:** Interactive circumstances need learners to explain concepts or exhibit comprehension.
- **Applying:** Gamified models allow learners to use knowledge in practical circumstances.
- **Analyzing:** Problem-solving tasks need learners to examine data, identify patterns, and calculate strategies.
- **Evaluating:** Peer assessments and thoughtful challenges stimulate judgment and assessment skills.
- **Creating:** Advanced gamified projects inspire learners to design solutions, transform, and produce new knowledge.

5.5 Personalized and Adaptive Learning

Gamification enables personalized learning experiences by adjusting effort, providing tailored feedback, and offering multiple paths for progression. Adaptive systems examine learner performance and adjust challenges to maintain optimal engagement and cognitive load, supporting both advanced learners and those needing additional platform. Personalized gamification boosts motivation, emphasizes strengths, and addresses individual learning needs.

5.6 Motivation and Engagement Theories

The pedagogical assimilation of gamification is secure by theories of **motivation**:

- **Self-Determination Theory (SDT):** Supports basic motivation through independence, competence, and relatedness.
- **Behaviorism:** Strengthens learning behaviors with rewards and feedback loops.
- **Flow Theory:** Maintains engagement by identical challenge to skill level.

5.7 Integrative Perspective

Gamification's assimilation with education is not merely additive but transformative. It makes experiential, problem-based, social, and intellectual approaches into consistent learning experiences that are engaging, measurable, and meaningful. When implemented thoughtfully:

- Students are more likely to continue in thought-provoking tasks.
- Learners experience independence, mastery, and social connection.
- Educators can support game mechanics with learning objectives, ensuring educational integrity.

Gamification functions as a connection between theory and practice, operationalizing learning principles in ways that are noticeable, cooperative, and motivating. It authenticates the role of games as powerful educational tools, not just as entertainment, transforming traditional classrooms into lively, learner-centered environments.

6. Benefits of Gamification in Learning Environments

Gamification offers a wide collection of benefits that boost both student learning outcomes and the overall educational experience. By assimilating game elements into instructional design, educators can nurture motivation, engagement, teamwork, and knowledge remembering. This section explores the primary advantages of gamification, drawing on speculative frameworks, experimental research, and practical applications.

6.1 Increased Motivation

One of the most important benefits of gamification is its ability to boost motivation, both basic and external. By including rewards, badges, and progress indicators, learners experience a sense of success and capability. Self-Determination Theory (SDT) supports this, suggesting that motivation arises when self-sufficiency, ability, and empathy are satisfied. Gamified systems allow learners to make choices, track progress, and receive acknowledgement, all of which stimulate continuous engagement and effort. For example, students completing levels in a language learning app like Duolingo are motivated to maintain lines and earn points, strengthening regular practice.

6.2 Enhanced Engagement

Gamification changes traditional, often passive learning into shared and captivating experiences. Challenges, hunts, and story-driven activities maintain learners' attention and inspire active participation. Engagement is further fortified through elements such as leaderboards and team challenges, which fuel friendly competition and teamwork. Research has shown that gamified classrooms experience higher rates of student participation and lower dropout rates compared to non-gamified environments.

6.3 Immediate Feedback and Continuous Improvement

Gamified learning environments deliver instant feedback on learner performance, letting students to identify errors, reflect, and improve immediately. Feedback loops, whether through points, progress bars, or educative guidance, encourage self-regulated learning and strengthen mastery. Instant feedback is particularly effective in skill-based disciplines like mathematics, programming, and language learning, where learners value from timely correction and support.

6.4 Collaboration and Social Learning

Many gamified systems mix combined elements, nurturing peer-to-peer learning and community building. Team challenges, co-operative quests, and group leaderboards encourage communication, cooperation, and collective problem-solving. Social learning theory emphasizes that learner's gain knowledge not only through personal experience but also by observing and interacting with peers. Gamification leverages this principle by providing structured opportunities for collaboration and social reinforcement.

6.5 Personalized and Adaptive Learning

Gamification supports personalized learning by allowing learners to progress at their own pace and engage with tasks suited to their skill level. Adaptive systems monitor learner performance and adjust difficulty, providing support for struggling learners while challenging advanced students. This flexibility enhances learning efficiency and ensures that each learner's unique needs are talked, promoting a more general educational experience.

6.6 Knowledge Retention and Application

By changing learning into active, experiential, and goal-oriented activities, gamification mends knowledge remembering and application. Learners are more likely to remember content they engage with actively and enjoyably. Virtual reality, problem-solving quests, and interactive exercises allow learners to apply speculative knowledge in practical scenarios, strengthening theoretical understanding and critical thinking skills.

6.7 Reduced Anxiety and Positive Learning Environment

Gamification can lower performance nervousness by creating a safe, playful, and structured learning environment. Learners are refreshed to experiment, make mistakes, and learn without fear of negative concerns. This emotionally safe environment promotes risk-taking, creativity, and deeper arrangement with content.

6.8 Enhanced Teacher Insights and Assessment

Gamified learning platforms offer rich data analytics that let educators to monitor progress, identify areas of difficulty, and tailor instruction. Teachers can measure not only educational performance but also engagement, teamwork, and problem-solving approaches. This data-driven perception allows more informed educational decisions and timely interferences.

6.9 Holistic Development

Beyond intellectual benefits, gamification supports sentimental and social development. Learners develop flexibility, time management, teamwork, and decision-making abilities. By integrating core motivation, teamwork, and problem-solving tests, gamification nurtures well-rounded learners furnished with both academic knowledge and essential life skills.

7. Challenges and Criticisms of Gamification

While gamification offers many benefits in educational settings, its application is not without experiments and criticisms. Understanding these limitations is crucial for designing effective and ethically responsible gamified learning experiences. This section examines the primary uncertainties, both practical and theoretical, associated with gamification in education.

7.1 Superficial Implementation

One of the most shared criticisms is the insincere or tokenistic use of gamification. Just adding points, badges, or leaderboards without mixing them into the learning objectives can result in “chocolate-covered education”—appealing on the surface but unproductive in promoting deep learning. When gamification is applied without educational alignment, it threatens distracting learners rather than nurturing meaningful engagement. Research emphasizes that educational gamification must be purposeful, with game mechanics line up to curriculum goals and intellectual outcomes.

7.2 Overemphasis on Competition

While competition can motivate learners, excessive reliance on leaderboards or rankings may produce negative effects, including stress, anxiety, and demotivation among lower-performing students. Some learners may feel depressed if they notice themselves as

consistently lagging behind peers. Educators must balance competitive elements with collaborative and cooperative features to ensure an inclusive and helpful learning environment.

7.3 Equity and Accessibility Issues

Gamification often trusts on digital tools, applications, or platforms, which can worsen differences among learners. Students with limited access to technology, internet connectivity, or devices may be disadvantaged. Additionally, game mechanics may not equally echo with all cultural backgrounds, learning styles, or age groups. Ensuring impartial access and culturally sensitive design is critical to prevent exclusion or unfair learning opportunities.

7.4 Teacher Preparedness and Professional Development

Effective gamification requires educators who are knowledgeable in both education and game design principles. Lack of training or understanding with gamified systems may lead to poorly intended experiences that fail to engage learners or meet learning objectives. Continuous professional development and support are necessary to empower teachers to implement gamification attentively, adding it with curriculum standards and learning assessments.

7.5 Cognitive Overload and Distraction

Improperly designed gamified environments can beat learners with too many challenges, notifications, or rewards. Excessive motivations may lead to intellectual overload, reducing focus and learning efficiency. Similarly, overstress on game mechanics can confuse learners from core content, line up gameplay over mastery of concepts. Balancing engagement with intellectual load is essential for supporting learning outcomes.

7.6 Ethical Concerns

Gamification raises ethical considerations regarding core versus external motivation, privacy, and behavioral influence. Over trust on external rewards may weaken core motivation, leading students to focus on rewards rather than learning. Furthermore, some platforms collect widespread learner data, raising privacy worries. Ethical gamification must respect independence, ensure transparency, and prioritize learner well-being.

7.7 Long-Term Sustainability

Maintaining learner engagement over time is exciting. Game elements such as points, badges, or flashes may lose uniqueness and influence if not periodically updated or varied. Supporting long-term motivation requires lively and growing gamification approaches, including adaptive challenges, narrative progression, and meaningful rewards that grow alongside learner expertise.

By admitting these challenges, educators and instructional designers can implement gamification attentively, ensuring that its benefits are maximized while minimizing unplanned negative effects. Thoughtful design, continuous evaluation, and alignment with educational goals are critical to achieving ethical, effective, and impactful gamified learning experiences.

8. Future Prospects and Innovations in Gamification

As education continues to evolve in the 21st century, gamification is composed to expand and integrate with developing technologies and educational innovations. While current implementations focus on points, badges, and leaderboards, the future of gamification lies in more adaptive, captivating, and personalized learning experiences. This section discovers styles, technological integrations, and innovations shaping the next generation of gamified education.

8.1 AI-Driven Personalization

Artificial Intelligence (AI) is set to change gamified learning by enabling adaptive, individualized learning **pathways**. AI algorithms can analyze learner behavior, performance, and engagement forms to tailor experiments, deliver personalized feedback, and improve difficulty levels. For example, an AI-driven gamified platform may adjust tasks to maintain optimal challenge, confirming learners remain in a state of flow, improving remembering, and minimizing frustration. AI can also identify learning gaps, suggest targeted resources, and predict future performance, enabling data-informed instructional decisions.

8.2 Immersive VR and AR Learning Environments

Virtual Reality (VR) and Augmented Reality (AR) provide highly realistic and interactive gamified experiences, allowing learners to involve with content in three-dimensional, realistic environments. VR models enable learners to drill complex skills—such as surgical procedures, engineering design, or historical exploration—without real-world values. AR applications cover digital content onto the physical environment, inspiring combined and experiential learning. These realistic technologies enhance engagement, motivation, and experiential understanding, taking gamification beyond old-style screens and points-based systems.

8.3 Gamified Assessment and Analytics

The future of gamification gives emphasis to assessment as an integral part of learning rather than a separate endpoint. Gamified valuations deliver continuous evaluation, combining learning with measurement. For instance, learners may earn points or badges for representing skills, completing challenges, or solving complex problems. Progressive analytics track performance trends, learning behaviors, and engagement metrics, enabling educators to customize instruction and identify areas for enhancement. This approach supports assessment with real-time feedback and actionable awareness, changing evaluation into an engaging, creative process.

8.4 Hybrid and Multimodal Learning

The future of gamification also supports hybrid and multi format education, blending face-to-face, online, and mobile learning experiences. Learners can stay engagement through multiple platforms, earning points, badges, and recognition through digital, shared, or classroom-based tasks. Such integration ensures that gamification is flexible, scalable, and accessible, providing continuity in learning experiences while supporting different learner needs and contexts.

8.5 Ethical and Inclusive Design

As gamification becomes classier, ethical considerations will figure future innovations. Developers and educators must confirm that gamified involvements respect learner independence, privacy, and cultural diversity. Complete design will furnish to diverse learning styles, abilities, and backgrounds, ensuring reasonable access and meaningful participation for all learners. Ethical gamification gives emphasis to purpose-driven rewards, transparent data use, and motivation approaches that strengthen learning rather than influence behavior.

8.6 Integration with Emerging Pedagogical Trends

Gamification is increasingly integrated with knowledge-building approach, experiential, and competency-based learning models, make parallel technology with educational objectives. Emerging fashions include:

- **Collaborative gamification**, nurturing teamwork and peer learning.
- **Narrative-driven quests**, connecting content to meaningful stories.
- **Skill-based progression systems** make straight challenges with capability development.
- **Cross-disciplinary gamification**, combining multiple subjects into interrelated gamified experiences.

9. Conclusion

Gamification in education denotes a conceptual and practical shift in how learning is designed, delivered, and experienced. By adding game design elements—such as points, badges, leaderboards, challenges, and narratives—into instructional approaches, educators can enhance motivation, engagement, teamwork, and knowledge remembering. This approach supports with multiple learning theories, including Self-Determination Theory, knowledge-building approach, Flow Theory, Social Learning Theory, and Experiential Learning, providing a strong theoretical foundation for its usefulness. The benefits of gamification are widespread: learners establish increased core and external motivation, improved focus, improved problem-solving skills, and deeper engagement with content. At the same time,

gamification nurtures collaboration, social learning, personalized pathways, and real-time feedback, creating learner-centered environments that furnish to different needs. Additionally, gamified learning supports holistic development, covering intellectual, sentimental, and social domains.

However, the application of gamification is not without challenges. Superficial use of game elements, overvalue on competition, justice and accessibility issues, intellectual overload, and ethical concerns can destabilize its effectiveness if not carefully addressed. Caring instructional design, alignment with curriculum objectives and consideration of learner range are critical for realizing the full potential of gamification.

Looking forward, developing technologies such as AI, VR/AR, adaptive systems, and sensory-rich platforms are set to change gamified education further. By utilizing these innovations, educators can create personalized, engaging, and meaningful learning experiences that go beyond old-style boundaries. When implemented ethically and strategically, gamification has the potential to redesign educational models, nurturing lifelong learning and preparing learners to grow well in the dynamic, technology-driven world of the 21st century.

Gamification is not just an educational fashion but a powerful educational approach that links the gap between motivation, engagement, and active learning. Its success depends on purposeful design, theoretical grounding, and continuous evaluation, ensuring that learners are empowered, motivated, and actively involved in their educational journey.

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BIOPOLYMERS: SUSTAINABLE AND INGENIOUS FOR FUTURE

Smita Behera

Department of Biotechnology,

Indian Institute of Management and Science, Bhubaneswar, Odisha, India.

Abstract

The current arena of life style is full of illusions; we are living in an era where everything is synthetic starting from toothbrush, carry bags to vehicles we are driving. Excessive use of synthetic polymers leads to accumulation and contamination of every sphere of the ecosystem that leads to environmental deterioration and contamination. To minimize these drawbacks with fulfilling the present needs, demands of biopolymers increased to next level with cradle to cradle economy and lower environmental crash. Biopolymers procured from various biological sources proved to be the best alternative with effective application in food, cosmetics, agriculture, pharmaceutical industries and many more. Biopolymers are the natural polymers extracted from nature including plants, animals, and microbes and mostly the polysaccharides, polypeptides, and polynucleotides. These biopolymers are the bioactive compounds which have gigantic applications in different fields like agriculture, cosmetics, pharmaceutical industries, research, and technology. These biopolymers play pivotal role in fulfilling the current need of environment and successfully implemented in human welfare. Research on extraction of biopolymers and its use in manufacture of products that can be used instead of chemosynthetic materials is the foremost need for producing complex molecule having biocompatibility, biodegradability and health promoting properties. The current review focuses on plant, animal, and microbe-based biopolymers and their applications in various industries.

Keywords: Biopolymers, sustainability, drug delivery, ecofriendly, microbial polysaccharides

1. Introduction

Biopolymers are macromolecules derived from living system including plants and agricultural waste, animals and microbes, possessing characteristics of easy availability, low cost, biodegradability, biocompatibility and as obtained from natural sources benefact with sustainable alternative to traditional available synthetic polymers. Biopolymers find extensive applications in biotechnology, including tissue engineering for scaffolds and bone regeneration, drug delivery for controlled release and encapsulation, wound healing with biocompatible dressings, and the creation of bio-medical devices like sutures. Their biocompatibility, biodegradability, and ability to be modified make them ideal for these applications. Biopolymers act like an interbridge between biology and material science

solving current disadvantages of man-made polymers in the field of medicine, cosmetics, food industry, tissue engineering, medicine delivery, and most hazardous plastic accumulation on earth [1-4]. The global biopolymers market size was estimated at USD 17.54 billion in 2023 and is projected to reach USD 38.69 billion by 2030, growing at a CAGR of 10.4% from 2024 to 2030 (Market Analysis Report).

Biopolymers sorted into three types comprising polynucleotides, polypeptides and polysaccharides exclusively involved in various biological processes that includes catalyzing chemical reactions, transporting molecules within the cells, cell adhesion, providing structural support (3, 4). Various sources like agro-waste, plants, microbes, aquatic animals etc. play significant role as a factory for the production of biopolymers. Biopolymers can be generated from bananas, maize, potatoes, tapioca, yams, rice, corn, wheat, cotton, sorghum, and barley leftover masses (2, 2a), as well as animal sources such as cattle, pigs, and other goods. Exopolysaccharides, terpenoids, flavonoids, proteins, polyhydroxyalkanoates etc. are derived from microbes are the important inception for the production of biopolymers.

The worldwide biopolymers market is expected to be worth USD 17.54 billion in 2023 and USD 38.69 billion by 2030, with a CAGR of 10.4% between 2024 and 2030. Day by day there is a mass accumulation of hazardous, synthetic and non-biodegradable polymers on earth that deleteriously affecting the life form likes microbes, animals, plant, human and overall, the ecosystem. So, it's high-time to shift towards nontoxic, life-friendly and environment supporting materials to overcome their drawbacks and live life in a pollution free, natural periphery.

Promising avenue for reducing the negative impact of synthetic plastic, chemically synthesized medicine with bulk side effects, carcinogenic cosmetics, and detrimental effect to agricultural field along with aquatic region, packaging quality and finally food quality is only the biopolymers. Hence, emphasis on production and utilization of biologically derived polymers by prioritizing ecofriendly and sustainable product characterized by their renewable origins, biodegradability, reduced carbon footprint, and non-toxicity, which offer an eco-friendly alternative to conventional, non-biodegradable petroleum-based plastics on its greatest peak. Here we have summarized some of the literatures that exclusively discussing about the sources of biopolymers, types and their application. They are proved to be highly valuable, cost effective, sustainable and safe for the ecosystem. So, according to the sources biopolymers re categorized as plant, animal and microbial biopolymers.

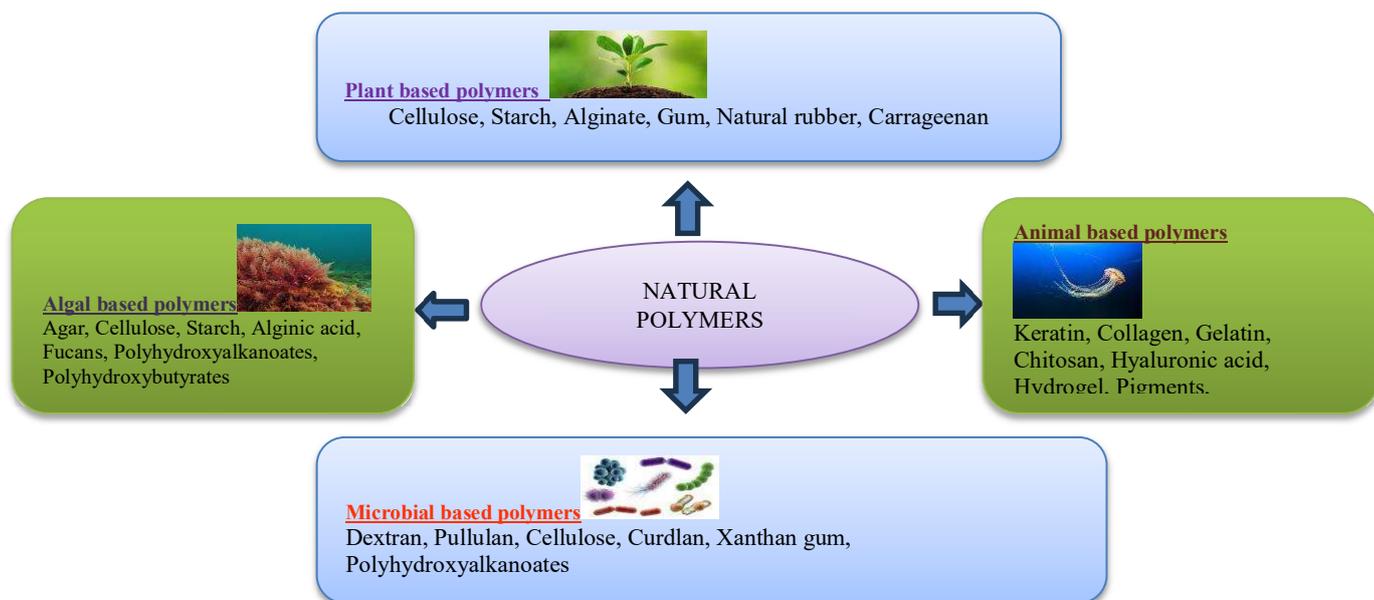


Fig. 1- Biopolymers from natural resources.

2. SOURCES OF BIOPOLYMERS

2.1. PLANT BASED BIO-POLYMERS

Biopolymers as we know are the biologically driven products that won't disturb the environment and health of human beings. Mostly plant-based biopolymers include cellulose, starch, lignin, pectin, alginate, polyhydroxyalkanoates, carrageenan, acacia gum and many more need to be revealed. These biopolymers are ecofriendly, structurally and biochemically diverged and effective and green alternative of petroleum-based products. Some of them are discussed below:

2.1.1. Cellulose

Cellulose is a polysaccharide and is most abundant biopolymer on earth. Primary source of cellulose is plants, woods, cotton and agricultural waste. It is a polymer of β -D glucose bonded with β (1-4) glycosidic bond. Because of the presence of interlinked -OH bonds it's possess toughest structure. Various methods and techniques like high-speed grinding and TEMPO- mediated oxidation, are employed to produce cellulose and its derivative like cellulose acetate, methyl-cellulose, hydroxypropyl cellulose, carboxymethyl cellulose, hydroxyethyl cellulose, microcrystalline cellulose and cellulose nanofibers (CNFs). Cellulose is mostly use for the production of paper and textile industries. However, its derivatives greatly involved in packaging, thickening, stabilizing and binding in food, pharmaceutical and cosmetic industries . Chipón *et al.*, 2022, blended potato starch with cellulose nanocrystals (CNCs), and the results showed that starch-NC composites are well suited for food packaging and the production of bio-plastics.

On the other hand, CNFs possessing exceptionally mechanical strength, ranging from 5 to 100 nm in diameter are found to have application in medical sector including, tissue

engineering, wound dressing, and medical implants. CNFs also play a transfiguring role in bioremediation, specifically water particularly water restoration and contamination control. The high surface area and reactivity of CNFs make them highly effective for adsorbing pollutants and heavy metals from wastewater. CNFs offer qualities that make them excellent for cosmetics, including high surface functionality, water-holding capacity, viscosity, and shear thinning.

Now days, cellulose-based mulches are being used to increase the fertility of agricultural fields, increasing decomposition organic material and nutrient retention of soil. This economic advantage motivates wider economic incorporation by farmers and supports sustainable agricultural practices.

2.1.2. Starch

Starch are the plant derived biopolymer composed of glucose units joined together by glycosidic bond i.e. α (1-4) and α (1-6). It is otherwise termed as storage form of energy in plants. It is readily available and low-cost polymers that have been found to exhibit properties of bio-plastic by certain modification. As plastics are synthetically manufacture and degradation process ranges several years, starch is evolving as a promising solution for its substitution. At present plastics is the second most extensively used packaging material, where addition of micro-plastics particles leaching to the food item or water is most common factor for environmental pollution and health deterioration.

Now a day's starch is been used as plasticizer, wound dressing, and starch in combination with polyhydroxyalkanoates provides good mechanical support in tissue engineering, surgical sutures, orthopedic pins, nerve guides, hydra-gels and bone/cartilage scaffolds .

2.1.3. Lignin, Pectin, Alginate

Lignin is a biopolymer occurs in cell wall of plants and like cellulose, impacts structural support. It the second most abundant biopolymer after cellulose on earth and possess properties like antimicrobial, antioxidant, excellent thermal stability and good alternatives for petroleum products. Currently, lignin from plant extract is being used as bio-plastic, carbon fiber and several lignin-based composites are used as polymers applicable as adhesive materials for woods panel, hydrogel activity and as an additive in mixtures to confer emulsifying or protective properties. Its polyphenol component exhibits great antioxidant properties and possesses properties like UV protectant. Lignin is a complex aromatic polymer composed of aromatic alcohols known as monolignols comprised of hydroxyl groups which exert its adhesive properties. Its key characteristic features of biodegradability, low toxicity, environmentally friendly and suitability for enzyme degradation attract researcher for biopolymer formulation.

Pectin

Pectin is now a day is also used as biopolymers mostly as gelling and thickening agent in food industry and as an initial component for bioplastic production because of its biocompatible, biodegradable and versatile nature. It is a polysaccharide complex incorporate of galacturonic acid chains and derived from agricultural field as a byproduct of vegetables and fruits. Demand for packaging material that to non-hazardous is the most arising concern in current scenario. Traditional method of packaging involves use of petroleum-based polymers that are non-biodegradable and affect normal population of soil micro flora and tremendously impairs the aquatic system. Pectin-based films used in active food packaging can reduce fat transfer, such as fat migration from fatty meals to packaging. Pectin based films proved to be excellent barrier to aroma, oxygen and water transfer when compared with synthetic polymers in food packaging sector. However, its mechanical properties are being modified when combined with polymers like alginate, starch, nanoparticles and incorporation of active agents like polyphenols to create composites for packaging, drug delivery, and tissue engineering.

Alginate

Alginate is the dynamic and multifunctional natural polymer obtained from seaweed found application in packaging, drug delivery wound dressing and many more. It's a polysaccharide compose of monomeric units, guluronic and mannuronic acid. It is a water-soluble polymer and forms gel in presence of divalent cations making suitable for edible coating and application in health sector. Polysaccharides such as pectin and alginate, which are developing biopolymers, have received a lot of interest in the development of biofilms and show potential for usage as natural polysaccharide-based packaging. Alginates are successfully incorporated in synthetic bone scaffold in lost bone substitute as more economical and low toxicity and gels are formulated by the use of guluronic acid and mannuronic rich alginates.

2.2. ANIMAL BASED BIO-POLYMER

Animal based biopolymers are the macromolecular complex similar to plant-based polymers serving great alternative for the available man-made polymers replacing its bad effect to environment and mankind. It includes chitosan, chitin, dextran, collagen, gelatine, hyaluronic acid, silk, keratin, glycogen and most important is the fabric i.e. wool. These biopolymers are generally extracted from body parts, fluid, extracellular matrix, excretory products, external structures like feathers, horns, hoofs and hairs. For example, catgut is a biopolymer primarily made from the purified collagen from intestine of sheep or cattle are the absorbable sutures used in health sectors. They possess excellent biocompatibility and degradability properties.

2.2.1. Chitosan

Chitosan is a derivative of chitin extracted from crustacean shells, fish scale, insects

and these are complex carbohydrates possessing application in biomedical, agricultural, cosmetics, and waste water treatment sector. Chemical extraction procedures, such as demineralization, deproteinization, and deacetylation, are commonly used for chitin extraction; however, this process degrades the polymer's properties; thus, biological extraction methods, such as enzymatic deproteinization and fermentations involving microorganisms, were used. These microbial processes offer environmentally sustainable and useful advantages as compared to standard chemical approaches. There are three main steps in the chitosan extraction process. Chitosan exhibits strong properties of edible films, for packaging purpose, preventing microbial development, retaining antioxidant properties and increase shelf life. Apart from this, these biopolymers have biomedical application including drug delivery, wound healing and surgical sutures. Studies suggest that chitosan nanoparticles have features that can be used as a carrier for different antigens, emerging prospective vaccines against bacterial diseases and illness. Several researches have proposed chitosan nanoparticles or microparticles as carriers for numerous antigens, indicating novel potential vaccinations against bacterial diseases.

2.2.2. Gelatin

Gelatin is the versatile biopolymers derived from the partially degraded product of collagen in animal connective tissue. This polymer provides easy accessibility its modification using methodology like cross linking to improve its properties. Animal gelatine is now proved to be excellent edible films for covering flesh that can prevent the deterioration and increase the shelf life by inhibiting microbial growth. Apart from its use in edible bio-composite film, it possesses great properties of shelf-life extension and avoiding microbial contamination in fruits and vegetables.

2.2.3. Keratin

Keratin is exclusively obtained from animal wool, hair, feathers, horns, hoofs. Keratins are insoluble fibrillar proteins produced in vertebrate epithelial cells that perform structural, protective, and cell differentiation functions. According to the report of Zheng and Suh, 1.5 G tones of CO₂ is emitted as greenhouse gas (GHG) by the plastics dump in the environment, however this expected to increase by 20250 up to 6.5 G tones. This can be reduced by the adoption of biopolymers and its application in production bioplastics and substitute materials. Keratin is now being used in printing textile in order to overcome the negative impact of chemically synthesized binder for pigment printing on textile fabrics.

2.2.4. Hyaluronic acid

Hyaluronic acids are the complex polysaccharides derived from animal tissues found profound application in cosmetics and pharmaceutical fields. The extracellular matrix of

vertebrate connective tissues, including cartilage, synovial fluid, and umbilical cords, contains repeating disaccharide units of D-glucuronic acid and N-acetylglucosamine. These polymers have fruitful application as a scaffold in tissue engineering, antiaging and moisturizing properties, hydrogels in drug delivery system.

2.3. MICROBE BASED POLYMER

Microorganisms are otherwise known as the miniature factory for the production functional products that can eliminate the over exploitation of plant and animal resources for biopolymer extraction. Although plant and animal sources of biopolymers exert beneficial impact on environment and health but overuse may lead to global warming and loss of habitat. Hence microbes are the exceptional fruitful resources for the stimulation, modification and extraction of bioactive materials that can be further utilized as biopolymers. Microscopic entities like bacteria, fungus, algae, protists and viruses are now being used and have found promising applications in different sector like agriculture, cosmetics, industrial hub and many more. Microbial biopolymers are mostly comprised of polyhydroxyalkanoates, polysaccharides, proteins and peptides.

2.3.1. Polyhydroxyalkanoates

Pollution due to fossil plastic is the major issue we are facing today, leading to accumulations of micro-plastics size <5 mm everywhere along with emission of CO₂ in the environment. Therefore, the global regulation is now centered on forbidding production, utilization and recycling of plastic materials. With this respect, biobased material like polyhydroxyalkanoates is emerged as a hope for the ideal replacement of these non-biodegradable polymers. Polyhydroxyalkanoates (PHAs) are biodegradable, biocompatible providing the benefits of synthetic polymer and it's economical. These bio-polymers are produced mainly by bacteria in the form of inclusion bodies and act as storage substances inside vegetative cells. PHAs can be turned into useable polymers using injection molding, blow molding, extrusion molding, compression molding, and additive manufacturing (Puppi, D.; Chiellini, F. Additive manufacture of PHA. During the melting process no chemical structure is altered, or no chemical modification is preferred, hence it retains its originality. PHA production was originally reported in 1926, when *Bacillus megaterium* was found to produce it. Later, bacteria such as *Alcaligenes lactus*, a mutant strain of *Azotobacter vinelandii*, and recombinant *Escherichia coli*, *Pseudomonas* sp., were discovered to manufacture these polymers. Furthermore, due to its bioplastic forming properties, it has biomedical uses such as tissue engineering, which involves healing or replacing damaged organs or tissues, and is predicted to expand from USD 9.9 billion at a 14.2% pace between 2019 and 2027. Because of their elasticity, durability, biodegradability, and biocompatibility,

PHAs have been used as feed for NP production and scaffolds for drug eluting .

2.3.2. Polysaccharides based biopolymers

Polysaccharides are the bioactive compounds produced by every living form as a secondary metabolite that significantly contributes survival, adaptability and multi-functional properties. Mostly microbes being omnipresent and widely distributed are used as a good source of polysaccharides. These are of two types, intracellular polysaccharide and extracellular polysaccharide. For cultivation, microbes are subjected to submerged fermentation method for good and desirable yield by altering the chemical component of the medium. These polysaccharides from different microbial sources with different structural diversity possess a variety of functional properties, having functional groups like carboxyl, hydroxyl, and amino. Polysaccharides are also known as mucoadhesive polymers due to their muco-adhesive properties. They are widely utilized as food additives, thickeners, and stabilizers. Polysaccharide materials have a wide range of uses, including food, food packaging, medicine delivery, tissue engineering, wound dressing, wastewater treatment, and bioremediation.

2.3.3. Proteins

Long chains of amino acid bonded by peptide bond of microbial origin also exert polymeric properties that can be implemented for good health and environmental restoration. These proteinaceous polymers have also been focused for their immense contribution in food, medicine, and packaging, acting as an alternative to petroleum-based plastics. Single cell proteins are being isolated from the microbial culture system including bacteria, cyanobacteria, fungi, yeast, and algae and used as a source of dietary protein. Spirulina grows quickly (doubling time of up to 2-3 hours), has 60-70% protein (dry weight), and contains almost all amino acids, including the essential ones.¹²⁸ A recent investigation found that the recovered proteins were Osborne fractionated: albumins 51.5%, globulins 2.4%, prolamins 46.1%, and no glutelin.¹²⁹ As a result, it is an excellent raw material for making protein-based bio plastics. Mycoprotein are the protein-rich biomass of certain fungi, for example *Fusarium venenatum*, which is widely used as a meat substitute under the brand name Quorn. Mycelia based composites which are dense network of fungal filaments from species like *Ganoderma lucidum* and *Pleurotus ostreatus* can be grown on agricultural waste (e.g., wheat straw, sugarcane bagasse) to create sustainable, biodegradable composites for use as thermal insulation and packaging materials. These materials are essentially a biopolymer matrix with the fungal proteins contributing to their structure and strength.

3. Conclusion

Biopolymer research demonstrates its transformative potential for satisfying modern society's material needs in a sustainable manner. Biopolymers are becoming increasingly

important in the creation of eco-friendly solutions across a wide range of industries, thanks to their unique features and environmental benefits. Biopolymers are making their impact as change agents by substituting single-use plastics in packaging, spurring innovation in the biomedical industry, advocating the cause of sustainable agriculture, and delivering more eco-conscious textile products.

New breakthroughs in biopolymer research continue to be made as the globe embraces sustainability. A future full of sophisticated, ecologically integrated biopolymer applications that genuinely prioritize our planet is promised by the ongoing advancements in material science. In order to positively contribute to environmental conservation and pioneer a world of bio-driven materials, enterprises must proactively evaluate the incorporation of biopolymers into their operations. Biopolymers represent a change toward long-term advancement rather than only being a fundamental material. Stakeholders can identify the inherent value they bring to the table by gaining a thorough understanding of their types and applications. This will ultimately facilitate a cooperative effort to responsibly construct a more sustainable future for future generations.

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**An overview on production, processing, biochemical and microbial testing of
Rabidi production & its microbial testing**

Author- Biswajit Behera¹, Lingaraj Murmu², Krishna Kumar Das*

¹Ruchi Factory, 675/1168, behind Reiki Mission, Khanna Nagar,

Industrial Estate Khapuria, Sriram, Cuttack, Odisha 753010

²P. G. Department of Environmental Science,

Fakir Mohan University, At/P.O. Nuapadhi, Balasore - 756089, Odisha

*Centre for Biotechnology,

Siksha 'O' Anusandhan deemed to be University, Bhubaneswar, Odisha, India-751003

Abstract

The Odisha State Co-operative Milk Producers' Federation Ltd. (OMFED), operating under the National Dairy Development Board (NDDDB), plays a pivotal role in the promotion, procurement, processing, and marketing of milk and milk products across Odisha. The present study aims to evaluate the biochemical and microbiological quality of milk and milk-based products produced under OMFED, with a particular focus on Rabidi—a traditional sweetened condensed milk product. Ensuring the safety and quality of such products is essential for consumer health, product shelf life, and compliance with regulatory standards.

The study encompasses a review of milk quality assessment parameters, including organoleptic, physico-chemical, and microbiological characteristics. Various laboratory tests—such as acidity determination, fat estimation using the Gerber method, total solids, specific gravity, and moisture analysis—were employed to assess product quality. Microbiological evaluation was carried out using standard dilution, sterilization, and incubation techniques on selective media such as VRBA, PCA, and PDA to quantify bacterial, yeast, and mold counts.

A detailed process flow for Rabidi production was standardized, beginning with filtration and controlled heating of whole milk, followed by concentration, sugar addition, and cold storage. Comparative microbial studies were conducted on Rabidi samples collected from the production vat and during cup filling to determine contamination points and quality variations. The findings highlight the significance of maintaining hygienic conditions, precise temperature control, and standardized biochemical testing throughout processing. The project not only enhanced practical understanding of dairy quality control and testing methodologies but also demonstrated the integration of biotechnological and food safety principles in traditional dairy product manufacturing. This study thus reinforces the need for rigorous quality assurance measures to ensure safe, high-quality dairy products under cooperative systems like OMFED.

Keywords: OMFED; National Dairy Development Board (NDDB); Rabidi production; biochemical and microbiological quality of milk and milk-based products.

Introduction

The Odisha State Co-operative Milk Producers' Federation Ltd. (OMFED) is a leading milk federation operating under the National Dairy Development Board (NDDB). Headquartered in Bhubaneswar, the capital of Odisha, OMFED serves as the apex cooperative organization for dairy development within the state. It is registered under the Cooperative Societies Act of 1962. The primary objectives of OMFED include the promotion, production, procurement, processing, and marketing of milk and milk-derived products across various regions of Odisha.

Milk quality can be evaluated through several analytical parameters that reflect the physiological condition of the producing animal, the milk's suitability for processing, and its hygienic status. These assessments generally involve methods that either directly or indirectly estimate the concentration of somatic cells and microbial populations in milk. Furthermore, such tests may provide detailed differentiation between cell types, offering diagnostic insights into milk quality and animal health.

In many countries, the acceptance or rejection of milk for processing or consumption is determined based on standard thresholds for somatic cell counts and bacterial load, which vary internationally. Additionally, several indirect or surrogate biochemical indicators—correlated with cellular and microbial activity—are employed as alternative measures of milk quality.

This project focuses on evaluating the principal methodologies used for assessing milk quality, emphasizing their comparative significance in terms of reliability and diagnostic value. It further explores the processes involved in milk handling, biochemical testing, and microbiological analysis of milk and milk-based products. Special attention is given to the preparation of Rabidi, including its biochemical composition and microbiological characteristics. The findings are examined in the context of their relevance to biotechnological applications as well as advancements in dairy and food technology.

Review On Omfed Products and Testing Techniques

Milk and milk products occupy a central position in the dietary habits of households worldwide. Their nutritional significance as a comprehensive source of essential nutrients is universally acknowledged. India, recognized as the world's largest producer of milk, holds a prominent place in global dairy production. The next crucial step for the nation is to strengthen its standing among leading milk and milk product-exporting countries. Globally, several nations have made substantial contributions to both the production and export of dairy commodities, which has, in turn, stimulated extensive research efforts in the field of dairy technology.

This section presents a concise review of existing literature, both national and international, focusing on the quality assessment of milk and milk products, the impact of seasonal variations, the use of adulterants and preservatives, and their overall influence on the dairy sector. A few common milk and milk products are shown in Figure 1.



Figure 1: Milk and Milk Products

Organoleptic Properties

Ghafoor et al. (1985) studied post-milking changes in 50 cow and 50 buffalo milk samples at ambient temperature (30–35°C) during July and August. No perceptible alteration in appearance, flavor, or odor was detected within the first four hours, indicating that raw milk can be stored safely at room temperature for that duration.

Wilson (1993), in his work at Massey University, New Zealand, investigated flavor variations before and after milking. Volatile aromatic compounds responsible for the “cow” or “sheep” flavor were identified as metabolic conjugates such as glucuronides, sulfates, and phosphates, which impart species-specific aromas. Lopez and Lindsay (1993) and Jahreis et al. (1993) found that changes in diet—particularly the inclusion of full-fat rapeseed meal—altered the taste and odor of milk, reducing overall sensory scores.

Anderssen (1995) emphasized that factors such as lactation stage, feeding, animal health, and hygiene during milking play critical roles in determining flavor quality. Routine sensory evaluation of milk was recommended to identify early deviations in quality.

Winkelman et al. (1999) analyzed genetic parameters influencing milk color in Friesian, Jersey, and crossbred cows. Milk color, measured at 450 nm absorbance, revealed that Jerseys produced milk with higher β -carotene content and more intense coloration. Espada and Vijverberg (2002) confirmed that milk color patterns remain consistent among udder quarters and over time, although higher fat and colostrum levels contribute to a yellowish hue.

Temiz and Hursit (2005) reported that blending soy milk with cow milk improved taste up to moderate inclusion levels, though excessive substitution decreased sensory acceptability. Dudrikova (2006) and Solah et al. (2007) further highlighted that feed type, animal health, and environmental conditions significantly influence milk color, aroma, and texture.

Physico-Chemical Parameters

Stefanovic et al. (1971) examined the effects of age and milking time on cow milk composition. They observed that evening milk generally contained higher total solids and fat than morning milk. Similar studies by Sontakke et al. (1978) on Deoni cow milk revealed average fat content around 4.3%, with consistent refractive indices (1.348) across individual and herd samples.

Veinoglou et al. (1982) compared milk samples from Bulgaria and Greece, finding notable seasonal variation, with fat content lowest during summer months. Ghatak et al. (1989) established that buffalo milk, though richer in fat and protein, exhibited lower heat stability compared to cow milk.

Kang et al. (1989) studied Korean native cows and found strong correlations among total solids, non-fat solids, and protein, allowing predictive equations for milk composition. Beniwal et al. (1994) examined distribution-level changes in milk and noted compositional differences due to partial withdrawal from cans, emphasizing the need for stricter sampling standards.

Further studies, including Cruz et al. (1997) and Sarkiyayi and Shehu (2011), demonstrated that factors such as breed, sex of calf, boiling, and fermentation influence milk's nutritional quality. Boiling reduced protein and fat contents, while fermentation mainly affected carbohydrate levels. Abolfazl et al. (2012) reported regional variations in fat and dry matter across different zones of East Azerbaijan, suggesting environmental and management effects on milk quality.

Biochemical and Microbiological Characteristics

Fleming (1973) evaluated bacteriological quality of water-cooled farm milk, noting a rise in microbial counts during warmer months. Mishra and Kulla (1989) found that milk from vendors and sweet shops in Kolkata had significantly higher microbial loads compared to dairy farms, underscoring the impact of handling and hygiene.

Reddy et al. (1990) observed that both raw and pasteurized milk exhibited increased bacterial counts during storage at 25–30°C, mainly due to inadequate handling. Similar conclusions were drawn by Rai and Dwivedi (1990) in Kanpur, where milk from organized dairies displayed superior bacteriological quality compared to that from street vendors.

Subsequent research by Lakhani et al. (1990) and Chatterjee et al. (2006) reinforced that machine milking and proper pasteurization significantly improve microbial quality. Hartmann et al. (2008) demonstrated that pre-cooling milk before bulk refrigeration reduced bacterial growth by 70%, highlighting the importance of rapid cooling post-milking.

Khan et al. (2008) and Parekh & Subhash (2008) employed both traditional plate count and PCR-based methods to evaluate microbial loads, recommending molecular diagnostics for rapid contamination detection. Further studies by Muhammad et al. (2009), Dahal et al. (2010), and Ali (2010) revealed that lack of refrigeration and unhygienic transportation practices substantially increase bacterial contamination.

Lues et al. (2010) and Lingathurai & Vellathurai (2011), identified similar concerns among small-scale dairy producers, linking poor sanitation and high ambient temperatures to microbial proliferation. Yuen et al. (2012) confirmed these findings in Malaysia, where bacterial loads were consistently higher at milk collection centers than at farms, indicating contamination during transport.

Milk Products

Dahi

Acharya and Yadav (1992) analyzed dahi samples from Rajasthan, reporting that only 20% met FSSAI fat standards. Sarkar et al. (1996) and Kamaruzzaman et al. (2002) observed significant variation in acidity and fat content, with plain dahi demonstrating better shelf life than fruit-based varieties. Younus et al. (2002) and Nahar et al. (2007) recorded comparable findings in Bangladesh and Pakistan, while Dewar et al. (2007) demonstrated dahi's nutritional benefits in improving hemoglobin and weight in malnourished children.

Salunkhe et al. (2008) and Kumbhar et al. (2010) emphasized the need for standardization and hygienic practices in unorganized sectors, as deviations in physico-chemical parameters often resulted in microbial spoilage.

Chhana

Tiwari and De (1976) reported average chhana composition with 41.6% fat and 3.5% moisture. Later studies (Kumar & Srinivasan, 1982; Goyal, 1991; Sharma & Reuter, 1991) investigated storage and packaging, recommending aluminum-foil-based laminates for optimal preservation. Gupta (2008) and Vidya et al. (2009) found that crossbred cow milk produced superior quality chhana compared to buffalo milk, and packaging materials and temperature significantly affected shelf life and sensory attributes.

Ghee

Ganguli and Jain (1972) proposed that ghee should contain $\leq 0.3\%$ moisture. Subsequent studies by Islam et al. (1982), Shekhar & Bhat (1983), and Suryanarayana & Sharma (1987) analyzed storage and processing impacts, observing that oxygen exposure and infrared radiation accelerated acidity and reduced shelf stability. Ghatak & Bandopadhyay (1989) and Banerjee et al. (2005) compared organized versus unorganized sectors, reporting that adulteration and poor packaging were prevalent in the latter. Rao et al. (2002) reiterated that cooperative dairies generally maintained compliance with legal quality standards, unlike unregulated markets.

Summary

Overall, the literature indicates that milk quality and its derivatives depend on a combination of animal physiology, feeding practices, handling hygiene, storage conditions, and processing technology. The studies collectively underscore the necessity for stringent quality control, efficient cold-chain systems, and adoption of modern testing methodologies to ensure the production of safe and superior dairy products — aligning with the goals of organizations such as OMFED in promoting high-quality milk and milk products across Odisha.

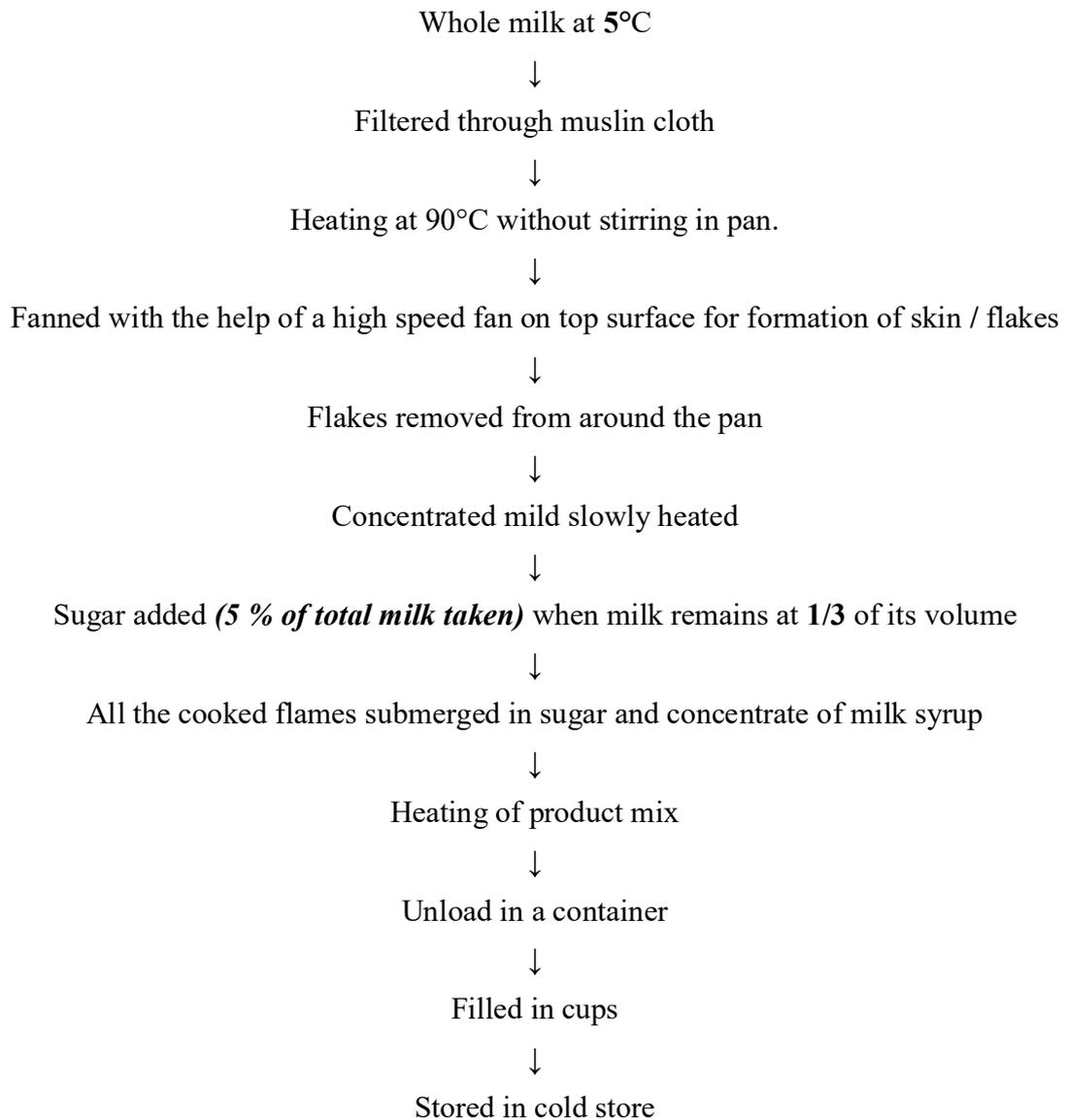
Objectives

1. This project will help to practically understand the basics of quality control, its application and procedures to maintain the quality of milk.
2. It also helps me to perform various lab tests to check the quality of milk and milk products before marketing.
3. It will demonstrate the processing of different milk products.
4. To practically understand the basics of milk procurement, processing, storage and packaging.
5. Along with theoretical knowledge the project will give an opportunity to exercises my technical skill while perform the various physical and chemical tests.
6. It simultaneously helps me to gain theoretical and practical knowledge about bacteriological tests.
7. To study the results of microbial growth in milk & milk products.
8. To study the morphology of bacteria by staining method.
9. To overview the development of acidity, microbial count and its shelf life study in rabidi.
10. The most attractive feature at this project is that it will be more practical oriented rather than theoretical.

Methodology

Different tests are applicable for different products of milk. Milk and milk products are like: Plain Curd, Sweet Curd, Lassi, Butter Milk, Sterilized Flavored Milk, Sterilized Chocolate Milk, Paneer, Ghee, Table Butter, Chhenapoda etc. have some common types of Biochemical tests for their safety, quality assurance and control. The common types of biochemical tests are like: **organoleptic test, acidity test, determination of fat, determination of total solid, specific gravity, lactometer reading, and moisture content** etc. These tests show the best quality and safety of the dairy products. But in my observation the product named "**RABIDI**" shows different methodologies for its production and quality controls. Below are the steps of production of Rabidi:

PROCESS OF RABIDI PRODUCTION



In the above steps the “**RABIDI**” was produced in the dairy farm but the tests for the quality and safety control are the main part to serve the product to the market for the commercial use. Due to the tests mentioned in the below figure the product can get the best quality certificate from the company and also from government.

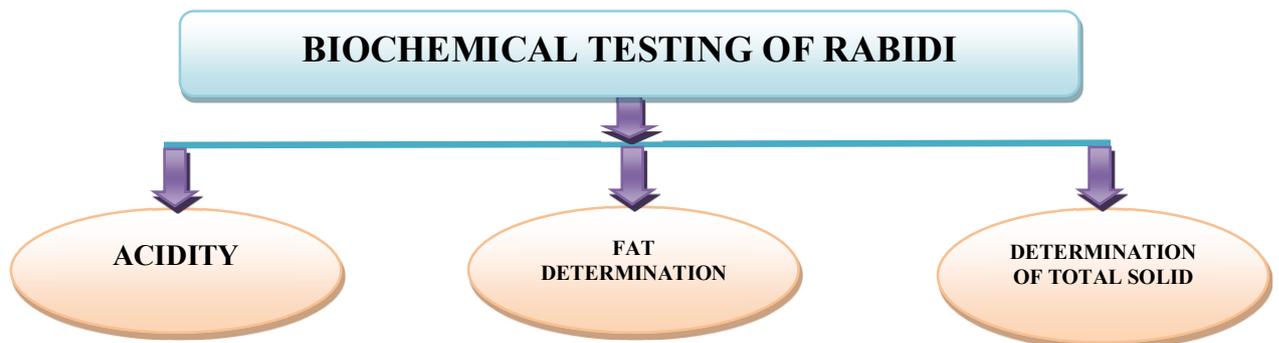


Figure.2: Biochemical Testing Of Rabidi

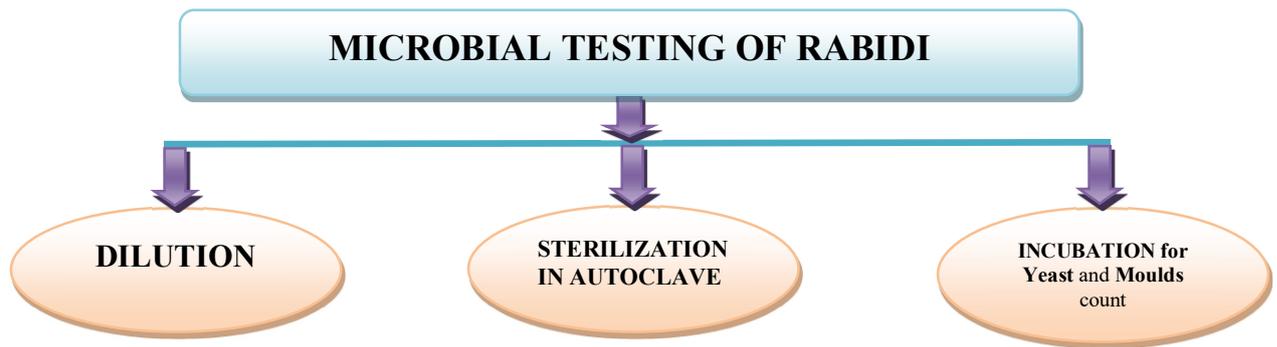


Figure.3: Microbial Testing Of Rabidi

Work plan for implement of methodology

- STEP-1:-** Milk sample used for Rabidi production is taken and its biochemical and microbial characteristics were studied.
- STEP-2:-** Acidity Test of well mixed Rabidi sample was taken and mixed with phenolphthalein indicator then titrated against **0.1 N NaOH** solutions.
- STEP-3:-** Fat Determination should be done by adding Gerber sulphuric acid, isoamyl alcohol.
- STEP-4:-** Determination of Total Solid should be done in an aluminum or ceramic dish by putting it in oven at **100°C ± 2°C** for **3** hours.
- STEP-5:-** Moisture content can be detected by Moisture Analyzer.
- STEP-6:-** Microbial Testing of Rabidi should be done by the processes like dilution, sterilization and incubation by using VRBA, PCA and PDA media for Yeast and Moulds count.
- STEP-7:-** Rabidi mix (Milk + Sugar) from Rabidi vat was taken and its properties were studied.
- STEP-8:-** Comparative microbiological studies were done between Rabidi from vat (*after completion of its production*) and Rabidi during cup filing.

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