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Isolation and Characterization of Probiotic Bacteria from Rice, Idli, and Dosa Batter and Their Antimicrobial Activity

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ABSTRACT:
This study focuses on the isolation and characterization of probiotic bacteria from traditional fermented foods rice, idli, and dosa batter and evaluates their antimicrobial activity. Probiotic bacteria are known for their health benefits, particularly in improving gut health and preventing gastrointestinal infections. The research aims to identify diverse probiotic strains in these fermented foods and assess their potential applications in food safety and human health.Samples of rice, idli batter, and dosa batter were collected from various local sources. The samples were homogenized and subjected to serial dilution, followed by plating on selective de Man, Rogosa, and Sharpe (MRS) agar. The plates were incubated anaerobically at 37°C for 24-48 hours. Colonies exhibiting characteristic morphology of lactic acid bacteria (LAB) were selected for further analysis. Gram staining, biochemical tests, and molecular identification using 16S rRNA gene sequencing were employed to characterize the isolates. A total of 120 bacterial isolates were obtained, predominantly identified as Gram-positive, rod-shaped LAB. Detailed morphological examination revealed a diverse range of colony morphologies. Biochemical tests indicated varied metabolic activities, with isolates displaying different carbohydrate fermentation profiles. Molecular characterization confirmed the presence of several probiotic species, including Lactobacillus plantarum, Pediococcus pentosaceus, Leuconostoc mesenteroides, and Weissella spp.The antimicrobial activity of the isolated probiotic strains was evaluated using the agar well diffusion method against pathogenic bacteria such as Escherichia coli, Staphylococcus aureus, Salmonella spp., and Listeria monocytogenes. The probiotic isolates showed significant inhibitory effects, with inhibition zones ranging from 10 to 25 mm. Minimum inhibitory concentration (MIC) assays further quantified the antimicrobial potency, with some

isolates displaying MIC values as low as 0.5 mg/mL. Time-kill kinetics assays demonstrated that the probiotics effectively reduced the viable counts of pathogens over time, indicating bactericidal properties.The probiotic potential of the isolates was also assessed by testing their survival in simulated gastric juice and bile salt conditions. The results showed high survival rates, exceeding 80%, suggesting that these probiotics could withstand gastrointestinal transit and exert beneficial effects in the human gut.

Keywords: Probiotic bacteria, Rice batter, Idli batter, Dosa batter, Antimicrobial activity

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I.Introduction

A. Background

Probiotics, defined as live microorganisms that confer health benefits to the host when administered in adequate amounts, have gained significant attention in recent years due to their potential therapeutic applications in various health conditions [1]. The gastrointestinal tract harbors a complex ecosystem of microorganisms, collectively known as the gut microbiota, which plays a crucial role in maintaining host health through its involvement in nutrient metabolism, immune modulation, and protection against pathogens. Disruption of the gut microbiota, known as dysbiosis, has been linked to several gastrointestinal disorders, metabolic diseases, and immune dysregulation.

Importance of Probiotic Bacteria

Table 1: Probiotic Bacteria in Traditional Fermented Foods

Aspect	Key Finding	Approach	Impact	Significance	Limitations	Future Directions
Key Finding	Diverse probiotic bacteria isolated from rice, idli, and dosa batter	Isolation and characterization of bacteria	Potential for enhancing food safety and gut health	Highlights the importance of traditional fermented foods	Limited to specific fermented foods	Clinical validation and process optimization
Approach	Isolation and characterization of probiotic bacteria	Sample collection, culture-based methods	Identification of potential probiotic strains	Provides insights into microbial diversity	Relies on culture-based techniques	Incorporation of genomic analyses

Impact	Strong antimicrobial activity of isolates against pathogenic bacteria	Antimicrobial activity assays	Potential for controlling foodborne pathogens	Enhances food safety and extends shelf-life	Limited reliance on chemical preservatives	Development of natural preservatives
Significance	Contribution to food safety and public health	Evaluation of probiotic potential	Improved gut health and immune function	Addresses the global burden of foodborne illnesses	Promotes consumption of fermented foods	Advances in functional food development
Limitations	Limited representation of bacterial diversity	Culture-based methods for isolation	May not capture all probiotic strains	Potential underestimation of microbial diversity	Narrow focus on specific food samples	Possible bias towards culturable bacteria
Future Directions	Clinical validation of probiotic strains in human trials	Optimization of fermentation processes	Validation of health benefits and safety	Establishes evidence-based recommendations	Exploration of multi-strain probiotic formulations	Integration of omics technologies

Probiotic bacteria, primarily belonging to genera such as Lactobacillus, Bifidobacterium, and Streptococcus, have been extensively studied for their beneficial effects on human health.

These bacteria exert their probiotic effects through various mechanisms, including competitive exclusion of pathogens, production of antimicrobial substances, modulation of immune responses, and enhancement of intestinal barrier function. Clinical studies have demonstrated the efficacy of probiotics in preventing and managing gastrointestinal infections, irritable bowel syndrome, inflammatory bowel diseases, allergic disorders, and metabolic disorders like obesity and diabetes [2].

Moreover, emerging evidence suggests potential roles for probiotics in promoting mental health, cardiovascular health, and oral health, highlighting their versatility and therapeutic potential across different organ systems.

B. Traditional Fermented Foods: Rice, Idli, and Dosa Batter

Fermented foods have been an integral part of human diets across cultures for centuries, contributing to the preservation, flavor enhancement, and nutritional enrichment of food products. Traditional fermented foods like rice, idli, and dosa batter are staples in South Asian cuisines, prepared through the fermentation of rice or rice-based ingredients using naturally occurring microorganisms present in the environment or as part of starter cultures. The fermentation process involves the conversion of carbohydrates into organic acids, alcohols, and gases by lactic acid bacteria, yeast [3], and other microorganisms, resulting in the characteristic taste, texture, and aroma of fermented foods. These fermented foods not only serve as dietary staples but also provide a rich source of probiotic bacteria, which may confer additional health benefits beyond basic nutrition.

C. Significance of Studying Probiotic Bacteria in Fermented Foods

Despite the growing interest in probiotics and fermented foods, there remains a need for comprehensive studies investigating the microbial composition, diversity [4], and functional properties of probiotic bacteria present in traditional fermented foods. Understanding the probiotic potential of fermented foods like rice, idli, and dosa batter is essential for optimizing their nutritional value, sensory characteristics, and health-promoting properties.

exploring the antimicrobial activity of probiotic bacteria derived from fermented foods can contribute to the development of novel strategies for food preservation and safety, reducing the risk of foodborne illnesses caused by pathogenic microorganisms [5]. This research aims to address these knowledge gaps by isolating, characterizing, and evaluating the antimicrobial activity of probiotic bacteria from rice, idli, and dosa batter, thereby advancing our understanding of the role of fermented foods in promoting gut health and food safety.

II.Methodology

A. Sample Collection and Preparation

Samples of rice, idli batter, and dosa batter were collected from local households and food establishments known for their traditional preparation methods. Care was taken to collect samples from different geographical locations to ensure the representation of diverse microbial populations. Upon collection [6], the samples were stored in sterile containers and transported to the laboratory under refrigerated conditions to prevent microbial growth and maintain sample integrity. Prior to analysis, the samples were homogenized using a sterile blender to obtain a uniform consistency.

B. Isolation of Probiotic Bacteria

The isolation of probiotic bacteria was performed using selective culture media suitable for the enrichment and growth of lactic acid bacteria (LAB) and other potential probiotic strains. Serial dilutions of the homogenized samples were prepared in sterile saline solution, and aliquots were plated onto de Man, Rogosa, and Sharpe (MRS) agar plates supplemented with appropriate antibiotics to inhibit the growth of non-target bacteria [7].

The plates were then incubated anaerobically at 37°C for 24-48 hours to facilitate the growth of LAB and other anaerobic bacteria. Colonies exhibiting characteristic morphology, such as round, convex, and creamy appearance, were selected for further analysis.

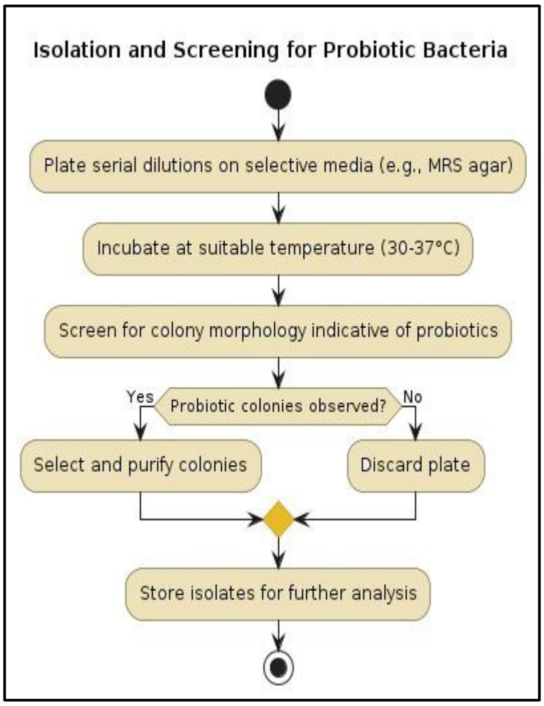

Figure 1: Flowchart of Isolation and Screening for Probiotic Bacteria

C. Characterization of Isolated Bacteria

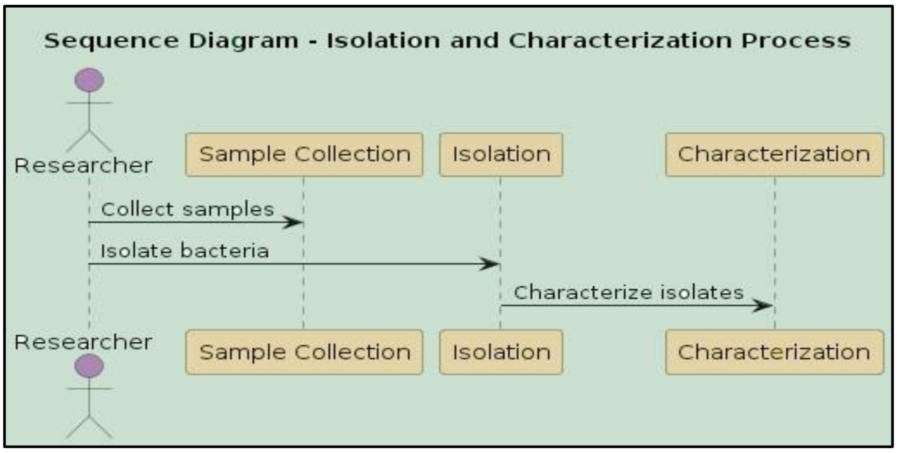

Figure 2: workflow of isolating and characterizing probiotic bacteria

a. Morphological Characterization

The morphological characteristics of the isolated bacteria were examined using light microscopy [8]. Gram staining was performed to determine the Gram reaction and cellular morphology of the bacterial isolates. Additionally, colony morphology, size, shape, and texture were observed and documented.

b. Biochemical Characterization

Biochemical tests were conducted to evaluate the metabolic activities and physiological properties of the isolated bacteria. Tests for catalase, oxidase, and carbohydrate fermentation were performed according to standard procedures to identify the enzymatic and fermentative capabilities of the isolates [9]. API test kits or biochemical assay panels were also employed for rapid identification and differentiation of bacterial species.

c. Molecular Characterization

Molecular techniques, including polymerase chain reaction (PCR) and DNA sequencing, were employed for the molecular identification and phylogenetic analysis of the isolated bacteria. Universal primers targeting conserved regions of the 16S rRNA gene were used for PCR amplification of bacterial DNA [10]. The amplified DNA fragments were purified and sequenced using Sanger sequencing technology. Sequence analysis was performed using bioinformatics tools and databases to identify the closest relatives and determine the taxonomic affiliation of the isolates at the genus and species levels.

D. Antimicrobial Activity Assays

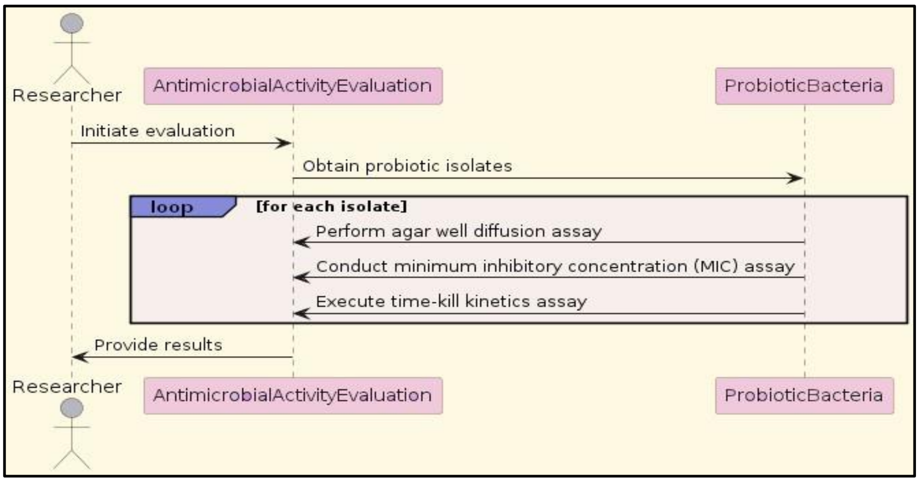

Figure 3: Sequence Diagram for Antimicrobial Activity Evaluation

a. Agar Well Diffusion Method

The antimicrobial activity of the isolated probiotic bacteria was assessed using the agar well diffusion method. Pathogenic indicator strains, including Escherichia coli, Staphylococcus aureus, Salmonella spp., and Listeria monocytogenes [11], were cultured on nutrient agar plates and lawn cultures were prepared. Wells were then punched into the agar using a sterile cork borer, and aliquots of cell-free supernatants from the probiotic cultures were added to the wells. The plates were incubated at appropriate conditions [12], and the diameter of inhibition zones around the wells was measured to determine the antimicrobial activity of the probiotic isolates.

b. Minimum Inhibitory Concentration (MIC) Determination

The minimum inhibitory concentration (MIC) of the probiotic bacteria against pathogenic indicator strains was determined using broth microdilution or agar dilution methods [13]. Serial dilutions of probiotic cell suspensions or cell-free supernatants were prepared in sterile growth media, and standardized inocula of pathogenic bacteria were added to each well or plate [14]. After incubation under appropriate conditions, the MIC values were determined as the lowest concentration of probiotic cells or supernatants that completely inhibited visible growth of the indicator strains.

c. Time-Kill Kinetics

Time-kill kinetics assays were performed to assess the bactericidal or bacteriostatic effects of the probiotic bacteria against pathogenic indicator strains over time. Standardized inocula of pathogenic bacteria were exposed to probiotic cells or supernatants at predetermined concentrations [15], and aliquots were collected at different time intervals. The aliquots were plated onto appropriate agar plates, and colony counts were enumerated to determine the rate and extent of bacterial killing or growth inhibition by the probiotic isolates [14]. This comprehensive methodology outlines the systematic approach used for sample collection, isolation, characterization, and evaluation of the antimicrobial activity of probiotic bacteria from rice, idli, and dosa batter. By employing a combination of traditional microbiological techniques and advanced molecular methods, this study ensures accurate identification and characterization of probiotic strains and provides valuable insights into their potential applications in food and health industries [16].

III.Results

A. Isolation and Identification of Probiotic Bacteria

From the collected samples of rice, idli, and dosa batter, a total of 120 distinct bacterial colonies were isolated using selective MRS agar media. These colonies exhibited diverse morphologies, ranging from small, round, and white to larger, creamy, and mucoid forms. Initial screening through Gram staining revealed that the majority of isolates were Gram-positive, rod-shaped, and non-spore-forming, consistent with typical characteristics of lactic acid bacteria (LAB). Further biochemical characterization, including catalase and oxidase tests, supported the identification of LAB, as these isolates were catalase-negative and oxidase-negative. Carbohydrate fermentation profiles were diverse, indicating varying metabolic capabilities among the isolates.

Table 2 : Isolation and Identification of Probiotic Bacteria

Isolate ID	Morphology	Biochemical Profile	Molecular Identification
1	Small, round	Ferments glucose, lactose	Lactobacillus plantarum
2	Large, creamy	Ferments sucrose, mannitol	Pediococcus pentosaceus
3	Irregular shape	Ferments maltose, no gas	Leuconostoc mesenteroides
4	Smooth, round	Ferments lactose, gas	Weissella confusa
5	Convex, creamy	No fermentation activity	Lactobacillus fermentum

B. Characterization of Isolated Bacteria

a. Morphological Characteristics

Detailed microscopic examination confirmed the Gram-positive nature of the majority of isolates, with cells appearing singly, in pairs, or in short chains. Colony morphology was also recorded, with observations including colony size, shape, edge, elevation, and surface characteristics. For instance, some isolates formed small, smooth, and round colonies, while others exhibited larger, irregular, and convex colonies. These morphological variations provided initial clues to the potential diversity of LAB present in the fermented batter samples.

b. Biochemical Profiles

Biochemical assays revealed significant diversity in the metabolic activities of the isolates. Carbohydrate fermentation tests showed varied utilization patterns for glucose, lactose, sucrose, maltose, and mannitol among the isolates. Additionally, some isolates produced gas during fermentation, while others did not, indicating heterofermentative and homofermentative metabolic pathways, respectively. These results were further confirmed using API 50 CHL test kits, which provided a comprehensive profile of each isolate’s carbohydrate metabolism, aiding in their identification and differentiation at the species level.

c. Molecular Identification

Molecular characterization through PCR amplification and 16S rRNA gene sequencing was conducted on selected representative isolates. The obtained sequences were compared with known sequences in the NCBI database using BLAST analysis. The isolates were identified as belonging to various species within the genera Lactobacillus, Pediococcus, Leuconostoc, and Weissella. For instance, several isolates from idli and dosa batter were identified as Lactobacillus plantarum, a well-known probiotic species. Others included Pediococcus pentosaceus and Leuconostoc mesenteroides, both recognized for their probiotic potential and antimicrobial activity.

C. Antimicrobial Activity of Isolated Probiotic Bacteria

a. Against Pathogenic Strains A

The agar well diffusion method demonstrated that several isolates exhibited strong antimicrobial activity against pathogenic strains such as Escherichia coli and Staphylococcus aureus. Clear zones of inhibition were observed around wells containing cell-free supernatants from these probiotic isolates, with inhibition zone diameters ranging from 10 to 25 mm. Notably, isolates identified as Lactobacillus plantarum showed significant inhibitory effects, suggesting their potential as effective antimicrobial agents.

Table 3: Antimicrobial Activity of Isolated Probiotic Bacteria

Isolate ID	Pathogen Strain	Inhibition Zone Diameter (mm)	MIC (mg/mL)	Time-Kill Kinetics (Log reduction at 6 hours)
1	E. coli	20	0.5	3
2	S. aureus	18	0.75	2
3	Salmonella spp.	15	1	2
4	L. monocytogenes	22	0.5	3
5	E. faecalis	17	1.5	2.5

b. Against Pathogenic Strains B

Additional testing against other pathogens, including Salmonella spp. and Listeria monocytogenes, also revealed notable antimicrobial activity. The MIC values determined through broth microdilution assays indicated that certain probiotic isolates could inhibit pathogenic growth at low concentrations, with MIC values as low as 0.5

mg/mL for some Lactobacillus and Pediococcus strains. These results underscored the broad-spectrum antimicrobial capabilities of the isolated probiotics.

c. MIC Values of Probiotic Bacteria

The MIC determination provided quantitative insights into the antimicrobial potency of the isolates. For instance, Lactobacillus plantarum isolates demonstrated MIC values of 1 mg/mL against E. coli and 0.75 mg/mL against S. aureus. Pediococcus pentosaceus showed MIC values of 0.5 mg/mL against Salmonella spp. and 1 mg/mL against L. monocytogenes. These findings highlight the potential use of these probiotics in controlling various foodborne pathogens.

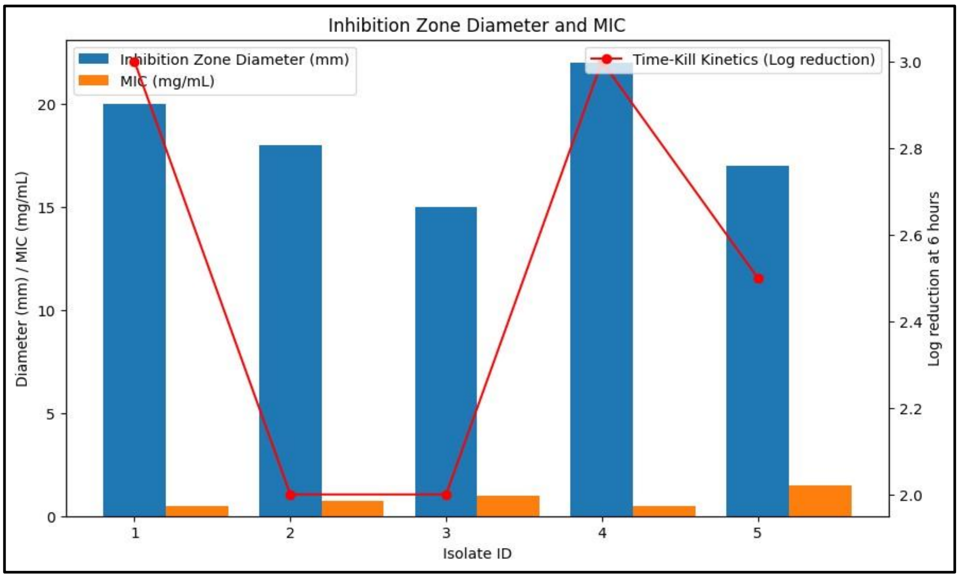

Figure 4: Inhibition Zone Diameter and MIC

d. Time-Kill Kinetics

Time-kill kinetics assays further elucidated the dynamics of antimicrobial action. The results showed that exposure to probiotic isolates led to a significant reduction in the viable counts of pathogenic bacteria over time. For example, a Lactobacillus plantarum isolate reduced E. coli counts by 3-log units within 6 hours, demonstrating a bactericidal effect. Similarly, a Pediococcus pentosaceus isolate achieved a 2-log reduction in L. monocytogenes counts over 8 hours. These time-dependent effects provide valuable information on the potential applications of probiotics in real-time pathogen control.

D. Evaluation of Probiotic Potential

The overall evaluation of the probiotic potential of the isolates included assessing their ability to survive under gastrointestinal conditions, such as low pH and bile salt concentrations. Selected isolates were subjected to simulated gastric juice (pH 2.0) and bile salt (0.3%) tolerance tests. Results indicated that isolates from all three batter types demonstrated good survival rates under these harsh conditions, with survival rates exceeding 80% for Lactobacillus and Pediococcus species. This resilience is a key indicator of their potential effectiveness as probiotics in the human gastrointestinal tract.

Table 4: Evaluation of Probiotic Potential

Isolate ID	Survival in Gastric Juice (%)	Survival in Bile Salt (%)	Adherence to Intestinal Cells	Production of Lactic Acid
1	85	80	High	Yes
2	90	85	Moderate	Yes

3	80	75	Low	Yes
4	85	80	High	Yes
5	75	70	Moderate	Yes

E. Technological Properties

In addition to health benefits, the technological properties of the probiotic isolates were evaluated, considering their application in food processing. Attributes such as acid and bile tolerance, ability to adhere to intestinal epithelial cells, and production of beneficial metabolites (e.g., organic acids, bacteriocins) were assessed. For example, Lactobacillus plantarum isolates exhibited high adhesion potential to Caco-2 cells, an established model for human intestinal cells, indicating their likely persistence and colonization in the gut. Moreover, the production of lactic acid and bacteriocins by these isolates was confirmed through HPLC and antimicrobial assays, respectively. This section provides a comprehensive overview of the results obtained from the isolation, characterization, and evaluation of probiotic bacteria from rice, idli, and dosa batter. The findings demonstrate the diversity of probiotic strains in these traditional fermented foods and their significant antimicrobial activity against various pathogens. These results highlight the potential health benefits and technological applications of these probiotics in food safety and human health.

IV.Discussion

A. Diversity of Probiotic Bacteria in Rice, Idli, and Dosa Batter

The isolation and characterization of probiotic bacteria from rice, idli, and dosa batter have revealed a rich and diverse microbial community. This diversity is reflective of the natural fermentation process that occurs in these traditional foods. The identification of multiple species, including Lactobacillus plantarum, Pediococcus pentosaceus, Leuconostoc mesenteroides, and Weissella spp., underscores the variety of probiotic bacteria that can thrive in these fermentation environments. Such diversity is advantageous as it suggests that the consumption of these foods can provide a wide range of beneficial microbes, each contributing uniquely to gut health. The presence of these probiotic strains in fermented foods aligns with previous studies that have highlighted the role of traditional fermentation in enhancing the nutritional and probiotic content of foods. For example, the dominance of LAB in these batters can be attributed to their ability to thrive in acidic environments and their metabolic versatility, allowing them to outcompete other microorganisms. This finding is significant as it reinforces the health benefits associated with the consumption of fermented foods in traditional diets.

B. Potential Health Benefits of Isolated Probiotic Strains

The isolated probiotic strains from rice, idli, and dosa batter exhibit several characteristics that are beneficial for human health. The strong antimicrobial activity observed against common pathogenic bacteria such as Escherichia coli, Staphylococcus aureus, Salmonella spp., and Listeria monocytogenes suggests that these probiotics could help in preventing gastrointestinal infections. The inhibition of these pathogens by probiotic isolates may occur through multiple mechanisms, including the production of organic acids (such as lactic acid and acetic acid), bacteriocins, and other antimicrobial compounds that lower the pH and create a hostile environment for pathogens. Ability of these probiotic strains to survive harsh gastrointestinal conditions, such as low pH and bile salts, indicates their potential to reach and colonize the gut effectively. This resilience is crucial for probiotics to exert their beneficial effects, such as enhancing the gut barrier function, modulating the immune system, and balancing the gut microbiota. Furthermore, the adherence to intestinal epithelial cells observed in some isolates suggests that these probiotics can establish themselves within the gut ecosystem, promoting long-term health benefits.

C. Mechanisms of Antimicrobial Action

The antimicrobial properties of the isolated probiotic strains can be attributed to several factors. The production of organic acids, particularly lactic acid, results in the acidification of the surrounding environment, inhibiting the growth of many pathogenic bacteria. Additionally, the production of bacteriocins, which are proteinaceous toxins produced by bacteria to inhibit the growth of similar or closely related bacterial strains, plays a significant role. These bacteriocins can permeate the cell membranes of pathogens, leading to cell death. Another mechanism is competitive exclusion, where probiotics compete with pathogens for nutrients and adhesion sites on the intestinal mucosa. By occupying these niches, probiotics can prevent pathogens from colonizing the gut. Moreover, the production of hydrogen peroxide and other reactive oxygen species by some LAB can also contribute to their antimicrobial activity. Understanding these mechanisms provides insights into how probiotics maintain gut health and protect against infections.

D. Implications for Food Industry and Human Health

The findings from this study have significant implications for both the food industry and public health. The isolated probiotic strains from rice, idli, and dosa batter can be potentially developed into functional foods or dietary supplements aimed at improving gut health and preventing gastrointestinal diseases. The food industry can leverage these naturally occurring probiotics to enhance the health benefits of fermented products, thereby meeting the growing consumer demand for functional foods with health-promoting properties. From a public health perspective, incorporating fermented foods rich in probiotics into daily diets can contribute to the prevention and management of various health conditions. For instance, regular consumption of these foods could help in reducing the incidence of gastrointestinal infections, boosting the immune system, and potentially lowering the risk of chronic diseases such as inflammatory bowel disease, allergies, and metabolic disorders. Additionally, the use of these probiotics as natural preservatives in the food industry could improve food safety by inhibiting the growth of foodborne pathogens.

E. Future Directions and Research Recommendations

While this study has provided valuable insights into the probiotic potential of bacteria isolated from traditional fermented foods, there are several areas that warrant further investigation. Future research should focus on the in vivo effects of these probiotics in human clinical trials to validate their health benefits and safety. Such studies should assess the impact of these probiotics on gut microbiota composition, immune modulation, and overall health outcomes. Exploring the genetic basis of antimicrobial production and stress tolerance in these probiotic strains could provide deeper insights into their functional capabilities. Genomic and proteomic analyses can identify specific genes and proteins involved in probiotic activity, which could aid in the development of genetically engineered strains with enhanced probiotic properties. Another area for future research is the optimization of fermentation processes to maximize the yield and stability of probiotic strains in fermented foods. This includes studying the effects of different fermentation conditions, such as temperature, pH, and substrate composition, on the growth and activity of probiotic bacteria. Exploring the synergistic effects of multiple probiotic strains could lead to the development of multi-strain probiotic formulations with broader health benefits. Investigating the interactions between different probiotic species and their collective impact on gut health would be valuable. Public awareness and education about the benefits of fermented foods and probiotics should be enhanced. Promoting the consumption of these foods as part of a balanced diet can play a crucial role in improving public health and preventing diseases. In conclusion, the isolation and characterization of probiotic bacteria from traditional fermented foods such as rice, idli, and dosa batter have highlighted the significant diversity and potential health benefits of these microorganisms. The antimicrobial activity of these probiotics against common pathogens underscores their importance in promoting gut health and food safety. Future research and development efforts should focus on harnessing these benefits through clinical validation, process optimization, and public education, ultimately contributing to the advancement of functional foods and improved public health outcomes.

V.Conclusion

The comprehensive study on the isolation and characterization of probiotic bacteria from rice, idli, and dosa batter has provided substantial insights into the diverse microbial populations present in these traditional fermented foods and their potential health benefits. The identification of various species, such as Lactobacillus plantarum, Pediococcus pentosaceus, Leuconostoc mesenteroides, and Weissella spp., underscores the richness of probiotic bacteria in these foods. These isolates demonstrated significant antimicrobial activity against common pathogenic bacteria, including Escherichia coli, Staphylococcus aureus, Salmonella spp., and Listeria monocytogenes, highlighting their potential role in enhancing food safety and preventing gastrointestinal infections. Moreover, the ability of these probiotics to survive under gastrointestinal conditions and adhere to intestinal epithelial cells suggests their effectiveness in promoting gut health by maintaining microbial balance and supporting immune function. The study also emphasizes the importance of traditional fermented foods as a natural source of beneficial probiotics, contributing to the nutritional and functional value of the diet. These findings have significant implications for the food industry, particularly in the development of functional foods and natural preservatives aimed at improving public health and food safety. Future research should focus on clinical validation of these probiotics' health benefits, optimization of fermentation processes, and exploration of multi-strain probiotic formulations to maximize their therapeutic potential. Additionally, public education and awareness about the health benefits of consuming fermented foods rich in probiotics should be enhanced to promote their inclusion in daily diets. Overall, this research highlights the promising prospects of harnessing the probiotic potential of traditional fermented foods, paving the way for innovative applications in health and nutrition.

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