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BACTERICIDAL POTENTIAL OF CRUDE BACTERIOCINS FROM LACTIC ACID BACTERIA ISOLATED FROM MOUSE GUT AGAINST SOME FOOD SPOILAGE BACTERIA

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ABSTRACT

The cells and secondary metabolites from Lactic Acid Bacteria (LAB) provide a biological food preservative suitable as an alternative to the use of chemical in extending food shelf life. The present research was aimed at examining the potential of crude bacteriocin from LAB isolated from the gut of mouse as a bio-control measure against the commonly encountered food spoilage bacteria. Compared to lactic acid bacteria (LAB) from other sources, including fermented foods, LAB from the mouse gut show better persistence and gut microbiota regulation. Their special adaptations to the gastrointestinal environment of mice increase their efficacy as probiotics by strengthening the intestinal barrier and boosting immune responses. Using standard microbiological methods, LABs were isolated from the gut of a mouse on De Mann Rogosa Agar (MRSA), characterized and identified. Crude bacteriocin was obtained from broth culture of the isolates and tested for antibacterial activity against Pseudomonas aeruginosa, Escherichia coli, Bacillus megaterium. Bacillus cereus and Staphylococcus aureus using agar well diffusion method. Four species of LAB were obtained and identified, three of which were Lactobacillus species 1, 3, and4 while one was a Lactococcus species. Crude bacteriocin from the Lactococcus species was the most effective against all the tested bacteria except B. megaterium, crude bacteriocin from Lactobacillus species 1and 3 were not effective against E. coli and B. megaterium while the crude bacteriocin from Lactobacillus species 4 was active against only S. aureus. Staphylococcus aureus was the most sensitive to the crude bacteriocins with an average zone of growth inhibition of 16.50 mm, followed by B. cereus (14.00 mm) and P. aeruginosa (13.50 mm), the least inhibition zone was in E. coli while B. megaterium was resistant (0.00 mm). This study shows that bacteriocin derived from Lactic Acid Bacteria (LAB) isolated from mouse gut demonstrates potential as a natural food preservative by effectively inhibiting various food spoilage bacteria.

Keywords: Lactic Acid Bacteria, Biopreservative, Bacteriocins, *Lactobacillus*, *Lactococcus*, Food Spoilage Bacteria

INTRODUCTION

Lactic acid bacteria (LAB) are versatile microbes from the firmicutes group, including genera like *Streptococcus, Bifidobacterium, Lactococcus*, and *Lactobacillus*, known for their benefits in food processing (Makela *et al.,* 2021). Their ability to produce growth-inhibitory substances, such as organic acids and bacteriocins, contributes to improved gut health, enhanced immune function, and disease prevention (Tannock, 2021and Bacigalupo *et al*., 2020). LAB maintain gut microbiota balance, inhibit pathogens, and enhance essential vitamins (Davis et al., 2022). Bacteriocins produced by LAB modulate gut health and regulate microbial populations (Lozupone *et al.,* 2021). Dysbiosis can disrupt gut health, but LAB can restore balance by competing with harmful bacteria (Ley *et al*., 2020; Kleerebezem and Vaughan, 2020). LAB from mouse gut can be isolated for use as probiotics, promoting health and preventing pathogen growth (Huang *et al*., 2020). Mouse gut LAB (lactic acid bacteria) is unique due to their distinct microbiota composition, influenced by adaptation and environmental factors (Huang *et al*., 2020). These LAB differ from those found in fermented foods in their specific strains and functional properties (Kleerebezem and Vaughan, 2020). While LAB in food mostly improve flavor and preservation, LAB in the mouse gut is essential for immune system and gut health modulation, which reflects their adaptation to the host's particular environment. (Davis *et al.,* 2022). Compared to lactic acid bacteria (LAB) from other sources, including fermented foods, LAB from the mouse gut show better persistence and gut microbiota regulation. Their special adaptations to the gastrointestinal environment of mice increase their efficacy as probiotics by strengthening the intestinal barrier and boosting immune responses. (Gänzle, 2022; O'Sullivan *et al.,* 2023 and Gänzle, 2023).

Previously used LAB species with antibacterial potential are the species of *Lactococcus, Pediococcus, Streptococcus, Bifidobacterium and Lactobacillus*. These bacteria have ability to produce bacteriocins with potential to inhibit the growth of food spoilage and foodborne pathogens (Pérez-Burillo *et al.,* 2021; Reid *et al*., 2020 and Gänzle, 2021). The functioning of LAB however depends on their adherence to the gut which promotes the synthesis of metabolites that support gut health (Morrison and Preston, 2021). The alarming inherent menace associated with food wastage due to spoilage bacteria, production of toxins in food during spoilage, toxicity of chemical used as food preservatives, and the health implication of consumption of foodborne pathogens have led to an insatiable demand for natural metabolites as food preservatives. This has necessitated the call for a search for novel bacteriocin producing bacteria that are indigenous and effective against commonly encounter food spoilage bacteria. The availability of these indigenous strains of biological preservative producing LAB isolates will tremendously act as measures that enhance local food processing and preservation, eliminate or reduce the use of toxic chemical as preservatives and alleviate the occurrence of foodborne diseases. This research is therefore aimed at evaluating the bacteriocinogenic property of LAB isolated from the gut of mouse against some food spoilage bacteria

MATERIALS AND METHODS

Collection and Preparation of Mouse and Test Bacteria

A mouse was obtained from the Biochemistry Department in Kwara State University, Malete and transported to the laboratory, the mouse was killed by euthanasia using chloroform, a method that ensures rapid and humane paralysis (Henderson *et al.,* 2013). Following euthanasia, the gut was aseptically removed and processed to isolate LAB.

The food spoilage organisms were isolated through sub-culturing from existing culture from the Department of Microbiology, University of Ilorin. This involves selecting colonies of interest from previous culture obtained from spoilt food samples. The culture was maintained on agar slant for further research. The test bacteria obtained were *Pseudomonas aeruginosa* and *Staphylococcus aureus*, *Escherichia coli*, *Bacillus cereus*, and *Bacillus megaterium*

Microbial Analysis

Isolation of Lactic Acid Bacteria from the Mouse Gut

The isolation of bacteria was accomplished using the streak plate method (El Kahlout *et al.,* 2018). The aseptically removed gut was dissected and a portion of the ileum was cut and lifted with a sterile forcep into a test tube where it was washed using sterile peptone water. The aliquot obtained was serially diluted in ten folds to the tenth power. One milliliter of the final dilution was plated on MRS (Man, Rogosa, and Sharpe) agar plates. The plates were incubated for 72 hours at 37°C in an anaerobic jar. Lactic Acid bacterial counts were determined using colony-counter in colony forming unit (CFU) on MRS agar. Due to mixed growth colonies on the plates, a close observation of morphological characterization of distinct pure colonies was made. Distinct colonies were sub cultured onto freshly prepared plates. Slants were used to maintain pure colonies for further study. (Eni, 2010 and Makinde *et al*., 2020) .

Identification of the Isolated Lactic Acid Bacteria

Morphological, colonial and biochemical were used to characterize and identify the isolates. Gram staining and biochemical tests for catalase and oxidase production, and sugar fermentation were carried out (Mannan *et al*., 2017; El Kahlout *et al.,* 2018).

Crude Bacteriocins Extraction

In a 250 ml Erlenmeyer flask with 100 ml of MRS broth, fresh cultures of each isolate were inoculated separately. The inoculation was autoclaved for 72 hours at 37°C. To acquire the cell-free culture supernatant (CFS), each sample was centrifuged at 6,000 rpm for 15 minutes at 4°C after incubation. The cell-free supernatant obtained was mixed with ammonium sulfate to neutralize the organic acid (70 % saturation), as it optimizes the precipitation of bacteriocins, enhancing yield and activity. This concentration has been shown to effectively separate active components while minimizing the loss of bioactivity (Gänzle, 2022). The mixture was placed in a cold incubator with rotary shaker for two hours at 4°C at 250 rpm. A rotary evaporator operating at 40°C was used to concentrate the crude bacteriocin obtained under vacuum (Islam *et al*., 2020). The crude bacteriocin extracts obtained from LAB isolates were tested against *Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Bacillus cereus, and Bacillus megaterium.* Positive controls, such as known bacteriocins like nisin, and negative controls, such as MRS broth alone, were included in the agar well diffusion assay to assess the antimicrobial activity accurately. (Gänzle, 2021; Kaur & Kaur, 2021 and Kaur & Kaur, 2022).

Determination of Antibacterial Activity of Bacteriocin

Antibacterial activity of the bacterial isolates against all the food spoilage bacteria tested was done using the agar well diffusion method (Islam *et al.,* 2020). Precisely one of each test bacterium (*Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Bacillus cereus,* and *Bacillus megaterium*) was grown overnight (18 hours) in a peptone broth to obtain actively growing cells, the broth culture was diluted favorably before 1 ml of the appropriate dilution was seeded onto Muller Hilton agar plates. Thereafter, 1ml of the cell-free crude bacteriocin was added to wells bored onto the surface of the agar plates with the aid of a sterile 6 mm cork borer. The plates were allowed to rest for penetration and even distribution before they were incubated for 24 hours at 37°C. The diameter of the inhibition zone surrounding the wells measure in mm was used to determine the antibacterial activity.

Statistical analysis was performed using one-way ANOVA to assess differences among treatment means, followed by Duncan's Multiple Range Test (DMRT) for post-hoc multiple comparisons at a significance level of $p < 0.05$. Means were first ranked, and pairwise differences were evaluated against studentized range–based critical values (q) multiplied by the standard error of the mean ($SE = \sqrt{(MSE/n)}$), where MSE was the ANOVA error term and n the number of replicates.

RESULTS AND DISCUSSION

The morphological and biochemical characteristics with sugar fermentation ability of the isolates are presented in Table 1. The isolates were Gram positive rods and coccus, negative for catalase, indole, oxidase activity, and citrate utilization. All the isolates were good fermenters of more than three out of all the sugar tested.

Table 1: Morphological and Biochemical Characteristics of the Lactic Acid Bacteria Isolates

Isolates	Colony Color	Gram Reaction	Morphology	Nitrate Reduction	Catalase	Indole	Oxidase	Citrate Utilization	Glucose	Lactose	Sucrose	Maltose	Mannitol	Fructose	Raffinose	Arabinose	Xylose
LAB 1	White	Gram-positive	Rod-shaped, non-motile, in chains	-	-	-	-	-	+	+	+	+	-	+	-	+	-
LAB 2	White	Gram-positive	Short rods	-	-	-	-	-	+	-	-	+	+	+	-	-	-
LAB 3	White	Gram-positive	Cocci shaped, appear in pairs	-	-	-	-	-	+	+	+	+	+	+	+	+	+
LAB 4	White	Gram-positive	Short cocci-shaped, occurs in pairs	+	+	-	-	+	+	+	+	+	+	+	-	+	+

Antibacterial Activity of the Crude Bacteriocin against the Test Bacteria

The crude bacteriocin extracts obtained from the LAB isolates were active against *Pseudomonas aeruginosa* and *Staphylococcus aureus, Escherichia coli, Bacillus cereus* but not active on *Bacillus megaterium.* The highest zone of inhibition was recorded on *P. aeruginosa* (13.33 ± 0.58) followed by *S. aureus* (14.33 ± 1.53) and *B. cereus* (14.00 ± 0.00) by *Lactobacillus* species 1. The crude bacteriocin from the *Lactococcus* species (LAB 2) produced inhibitory effect on *E. coli* (13.67 ± 0.58) and *B. cereus* (14.67 ± 0.58). Crude bacteriocin from *Lactobacillus* species 3 (LAB 3) inhibited *S. aureus* (17.33 ± 0.58), *P. aeruginosa* (12.67 ± 0.58) and *B. cereus* (11.67 ± 0.58). The crude bacteriocin from *Lactobacillus* species 4 (LAB 4) was only able to inhibit the growth of *S. aureus* (13.33 ± 0.58). None of the crude bacteriocins from the extracts was active against *B. megaterium* growth. The antibacterial activity of crude bacteriocins from the LAB2 and 3 were more potent and the activities were significantly different. Statistical analysis through Duncan tests confirmed the significance of the obtained results between treatments.

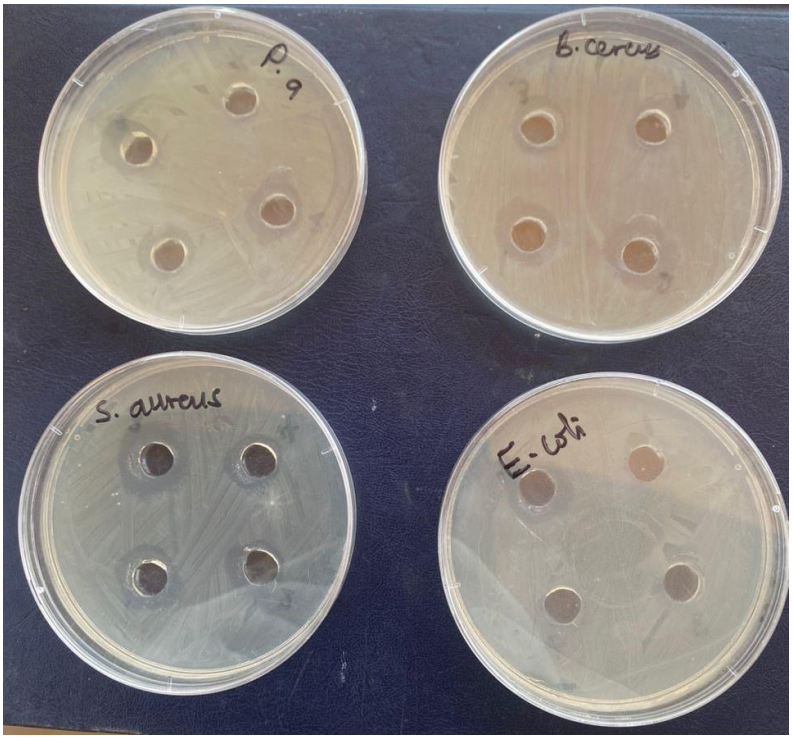

Plate 1: Pictorial representation of the antibacterial activity of the LAB isolates against Pseudomonas aeruginosa, B. cereus, S. aureus, and E. coli

Table 2: Antibacterial Activity Crude Bacteriocins from LABs Diameter of inhibition zone (mm)

LAB Isolates	Organisms				
	P. aeruginosa	***S. aureus***	***E. coli***	***B. cereus***	***B. megaterium***
Lactobacillus casei	13.33±0.58^{c}	14.33±1.53^{a}	0.00±0.00^{a}	14.00±0.00^{c}	0.00±0.00
Lactobacillus fermentum	12.00±0.00^{b}	12.50±0.71^{a}	13.67±0.58^{b}	14.67+0.58^{c}	0.00±0.00
Lactococcus lactics	12.67±0.58^{bc}	17.33±0.58^{b}	0.00±0.00^{a}	11.67+0.58^{b}	0.00±0.00
Pediococcus pentosaceus	0.00±0.00^{a}	13.33±0.58^{a}	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00

Mean values are presented as mean ± SEM (standard error of the mean), with n = 3 independent biological replicates.

Superscript letters within each column indicate statistically significant differences among means ($p < 0.05$), determined by one-way ANOVA followed by Duncan's Multiple Range Test (DMRT) using studentized range (q) values for n = 3

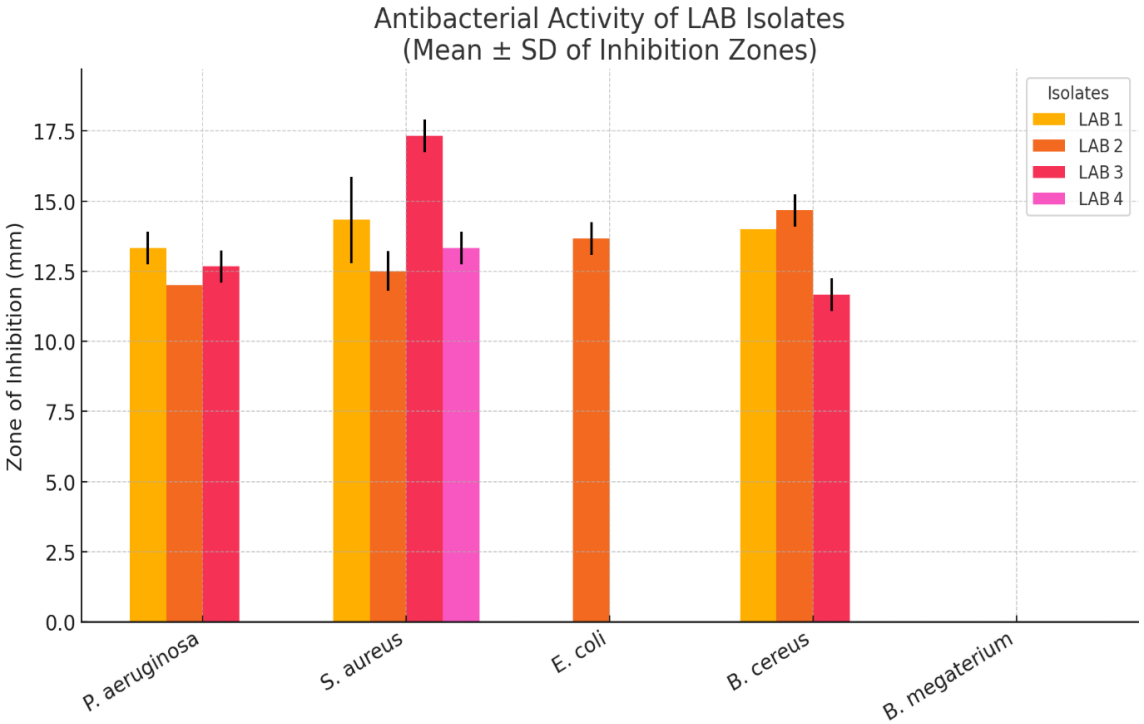

Figure 1: Antibacterial Activity of LAB Isolate

Discussion

The current study focused on the isolation of Lactic Acid Bacteria with potential probiotic functions explored from Mouse gut. In the present investigation, four potential probiotic isolates were identified as three *Lactobacillus* species (LAB 1, LAB 3 and LAB 4) and a *Lactococcus* species (LAB 2). The isolation of these bacteria from the mouse gut supported previous report on the presence of and the dominant population of this group of bacteria in the gut of monogastric animals including mouse. The LAB are free living dwellers of the gut (Duar *et al*., 2017), previous reports have also isolated *Lactobacillus* species (*Lactobacillus acidophilus and Lactobacillus fermentum)* from human, pigs, hamsters, and horses' gut (Duar *et al.,* 2017).

Their association with the gut could suggest their potential for use as probiotic organisms to promote gut health (Sorescu *et al.*, 2020), the isolated LAB species could also serve in particular in developing probiotic bacteria for the mouse species because probiotic bacteria sometimes could be host-adapted and have a high ecological fitness in their host or related species. Moreover, this higher fitness is relevant in the process of outcompeting the pathogens.

The ability of the LAB species to perform conversion of several types of simple and disaccharide sugar into acid suggest a wide fermentative potential that could be of advantage in the dairy and other industries for food processing. The organic acid formed as a result of the conversion of sugar into lactic acids and other acids could be used as food preservative to extend shelf life. The acids produced often lowers or reduce pH and thus, could inhibit the growth of many bacteria spoilage bacteria which are normally neutrophiles. Morphological and biochemical characteristics of this LAB isolates were in tandem with previous report from similar work (Sorescu *et al.*, 2019 and Sorescu *et al*., 2020).

In conformity to the observation of Sorescu et al. (2020), the isolated from the mouse gut, can be important for developing probiotic compounds for the same mouse species because they are host-adapted and have a high ecological fitness. Moreover, this higher fitness is relevant in the process of outcompeting the pathogens.

Differentiation of *Lactobacillus species* was performed as described before by Sorescu *et al*. (2019) and Sorescu *et al.* (2020) mainly on the basis of some morphological characters, some cultural characters and especially, biochemical characters.

Bacteriocins which are ribosomal synthetized proteins have similar actions to antibiotics and could serve same purpose in food. The crude bacteriocins from the LAB isolated in this study were very active to inhibit the growth of all the tested food spoilage bacteria except *Bacillus megaterium*. Previous authors have reported the antibacterial activity of bacteriocin against commonly encountered foodborne bacteria (Adedayo and Abdulkareem, 2024; Mohammaddoos *et al.,* 2015). The ability of the crude bacteriocins to inhibit the growth of *Pseudomonas aeruginosa* represents a significant threat to both public health and food safety, primarily due to its intrinsic resistance to a broad range of antibiotics. This resistance is largely attributed to the production of hydrolytic enzymes, such as β-lactamases, and the presence of multiple virulence-associated genes (Breidenstein *et al.,* 2011). *Pseudomonas aeruginosa* shows natural resistance to bacteriocins like nisin due to its outer membrane barrier and efflux mechanisms, highlighting the need for more effective antimicrobial agents (Gharsallaoui et al., 2016). *Pseudomonas aeruginosa* is now emerging as opportunistic pathogen with ability to form biofilm in food pipes during processing. Hence, having a bacteriocin that could limit its growth incorporated into foods during production and

distribution lines will enhance shelf life and product safety (Adedayo and Abdulkareem, 2024).

Escherichia coli, Staphylococcus aureus and *Bacillus cereus* were also very sensitive to the crude bacteriocins. *Bacillus megaterium* may resist LAB due to its thick cell wall and potential bacteriocin-neutralizing mechanisms, while *Lactococcus spp*. likely demonstrated higher levels of activity by producing a number of bacteriocins that targeted several locations. (Cotter *et al.,* 2005). These bacteria were mostly foodborne pathogens and are often occurring in spoilt food, and especially in ready to eat food. Toxin producing species of these bacterial release poisonous metabolites into foods during spoilage in store or prior to consumption after processing. The heterotrophic nature of these bacteria makes them ready tools for food spoilage during which they release certain metabolites into food rendering it unfit for consumption. They are also reported to have genes for antibiotic resistance and virulence factors that enhance pathogenicity. The presence of methicillin resistance *Staphylococcus aureus* was reported in open displayed ready to eat fish and fruit during distribution line (Adedayo and Yusuf, 2024; Adedayo *et al.,* 2024). The close association of the test organisms to human enhances their contamination of food and invariably they get consumed. *Bacillus cereus* though a soil dweller, has been isolated from food as spoilage and pathogenic bacteria (Ayilara *et al*., 2023).

The bacteriocin genic property of the crude extracts from the isolated *Lactobacillus* and *Lactococcus* species against the *Pseudomonas aeruginosa, B. cereus, S. aureus*, and *E. coli* suggests that the isolates or their metabolites if incorporated into food during processing could prevent the growth of the bacteria. However, the crude bacteriocins were not able to inhibit the growth of *B. megaterium* though it inhibited the growth of *B. cereus*, which is a closely related organism. The probable reason for this might be a subject for future research. The activity of the crude bacteriocin was both on the closely related Gram-positive *S. aureus* and *B. cereus* as well as the Gram-negative *P. aeruginosa* and *E. coli* indicating a wide spectrum of activity. Bacteriocins are usually more effective on closely related strains than more distant strains but the observations in this study deviates from the former reports by been potent on many species of food spoilage bacteria. The bacteriocins in pure form could be engaged in the food processing and distribution lines to replace the use of common antibiotics in food. Because they can inhibit pathogens and prolong shelf life, crude bacteriocins from lactic acid bacteria are used as natural food preservatives. They also remain stable in real-world settings like heat, pH changes, and cold storage, and encapsulation techniques further increase their efficacy and controlled release in food systems (Fotso Techeu et al., 2022; Mohammed et al., and 2024; Perez et al., 2023). The ripple effect of which will include safer food, extended shelf life and reduction in the development and spread of community acquired antibiotic resistance through consuming food.

CONCLUSION

The study isolated *Lactobacillus* and *Lactococcus* species in this study were bacteriocin producers and the crude bacteriocins from the LABs were variously active against the tested food spoilage bacteria except *Bacillus megaterium* which showed resistant to all the crude bacteriocins from the isolated LAB. In this study, the probiotics produced by the lactic acid bacteria isolated from mouse gut are considered to be effective for antibacterial agents and safe to the host animal. The availability of these indigenous strains of biological preservative producing LAB isolates will tremendously act as measures that enhance local food processing and preservation, eliminate or reduce the use of toxic chemical as preservatives and alleviate the occurrence of foodborne diseases

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REFERENCES

Adedayo, M. R. and Abdulkareem T. O. (2024). Bacteriocinogenic Activity of *Lysinibacillus fusiformis* NR_042072.1 Isolated from Cow Milk; *Natural and Applied Science Journal,* 7(2): 29-38. https://doi.org/10.38061/idunas.1491313

Adedayo, M.R., Emmanuel, T.O., Ajiboye, A.E. (2024). Beta-Lactamase production and antibiotic susceptibility screening of *Staphylococus aureus* isolated from ready-to-eat fruits sold in some parts of Offa Metropolis, Nigeria. *Journal of Food Safety and Hygiene*; 10 (1): 22-33, https://doi.org/10.18502/jfsh.v10i1.16442

Ayilara, T. T., Awe, S. and Adedayo, M. R. (2023). Toxigenic Profiling and Antibiotic Resistance of *Baclllus cereus* Strains Isolated from Food Consumed by School Children In Ilorin Metropolis, *Pan African Journal of Life Sciences, LAUTECH;* 7(2); 654-661; https://doi.org/10.36108/pajols/3202/70.0240

Adedayo, M. R. and Yusuf. A. O. (2024). Detection of Methicilin-resistant *Staphylococcus aureus* in open displayed Ready-to-eat fish in some markets in Ilorin; *Technoscience Journal for Community Development in Africa* 3 (1): 190-198. https://journals.kwasu.edu.ng/index.php/technoscience/article/view/264

Bacigalupo, M., Dufour, M., and Esteve-Zarzoso, B. (2020). Bacteriocins of lactic acid bacteria as biotechnological tools in food and pharmaceuticals: Current applications and future prospects. *Biocatalysis and Agricultural Biotechnology*, 28, 101750. https://doi.org/10.1016/j.bcab.2020.101750

Breidenstein, E. B. M., de la Fuente-Núñez, C., and Hancock, R. E. W. (2011). Pseudomonas aeruginosa: All roads lead to resistance. *Trends in Microbiology*, 19(8), 419–426. https://doi.org/10.1016/j.tim.2011.04.005

Cotter, P. D., Hill, C., and Ross, R. P. (2005). Bacteriocins: Developing innate immunity for food. *Nature Reviews Microbiology*, 3(10), 777–788. https://www.nature.com/articles/nrmicro1273

Davis, E. L., Miller, K. M. and Foster, J. W. (2022). Antimicrobial properties of lactic acid bacteria and their role in gut health. *Journal of Applied Microbiology*, 133(2), 492–501.

Duar R.M., Lin X.B., Zheng J, Martino M.E., Grenier T., and Munor MEP. (2017). Lifestyles in transition: evolution and natural history of the genus *Lactobacillus.* Review. *FEMS Microbiology*;30(41):27-48 https://doi.org/10.1093/femsre/fux030

Eni, A.O., Oluwawemitani, A, and Solomon, O.U., (2010) Microbial quality of fruits and vegetables sold in Sango Ota, Nigeria. *African Journal of Food Science*.4(1):291-296. at: http://www.academicjournals.org/journal/AJFS/article-full-text-pdf/298CAF223943

El Kahlout, K. E., El Quqa, I. M., El Hindi, M. W., and El Bashiti, T. A. (2018). Isolation, identification, and characterization of lactic acid bacteria from traditional fermented milk in Palestine. *Journal of Dairy Science*, 101(5), 1–10. https://doi.org/10.4236/aim.2018.812068

Fotso Techeu, U. D., Sadiku, M. N., Ennahar, S., and Sanni, A. I. (2022). Characterization of bacteriocin produced by Lactococcus lactis F01 and its application as a bio-preservative in fish sausage. *Heliyon*, 8(12), e11916. https://doi.org/10.1016/j.heliyon.2022.e11916

Gänzle, M. G. (2021a). Adherence mechanisms of lactic acid bacteria in the gastrointestinal tract. *Microorganisms,* 9(3), 646. https://doi.org/10.3390/microorganisms9030646

Gänzle, M. G. (2021b). Bacteriocins: Properties and potential use as antimicrobials. *Frontiers in Microbiology,* 12, 876147. https://doi.org/10.3389/fmicb.2021.876147

Gänzle, M. G. (2022). Bacteriocins from lactic acid bacteria: Strategies for the bioprotection of food. *Frontiers in Food Science and Technology,* 12, 1439891. https://doi.org/10.3389/frfst.2024.1439891

Gänzle, M. G. (2023). The bacteriocins produced by lactic acid bacteria and the promising applications in promoting gastrointestinal health. *Animals,* 11(4), 979. https://doi.org/10.3390/ani11040979

Gharsallaoui, A., Oulahal, N., Joly, C., and Degraeve, P. (2016). Nisin as a food preservative: Part 1: Physicochemical properties, antimicrobial activity, and main uses. Critical Reviews in *Food Science and Nutrition*, 56(8), 1262–1274. https://doi.org/10.1080/10408398.2013.763765

Henderson, J. A., Smith, R. A., and Jones, T. L. (2013). Methods for the humane euthanasia of laboratory animals. *Journal of Laboratory Animal Science,* 53(2), 123–130. https://doi.org/10.1002/jlas.00012

Huang, J., Wang, Y., and Tang, H. (2020). The influence of lactic acid bacteria on gut health and immune responses in animal models. *Journal of Immunology*, 48(6), 345–355. https://doi.org/10.1002/jim.12012

Islam, M. T., Rahman, M. M., Hossain, M. S., and Sultana, S. (2020). Antibacterial activity of lactic acid bacteria isolated from traditional fermented foods. *Journal of Food Science and Technology,* 57(5), 2101–2110. https://doi.org/10.1007/s11483-020-01873-5

Islam, R., Hossain, M., Alam, M., Uddin, M., Rony, M., Imran, M., and Alam, M. (2020). Antibacterial activity of lactic acid bacteria and extraction of bacteriocin protein. *Advances in Bioscience and Biotechnology*, 11, 49–59. https://doi.org/10.4236/abb.2020.111005

Kaur, S., and Kaur, R. (2021). Characterization and profiling of bacteriocin-like substances. *Microbiology Research*, 12, Article 8374546. https://doi.org/10.1099/acmi.0.000234

Kaur, R., and Kaur, S. (2022). Antimicrobial effect of partially purified bacteriocins on Pseudomonas aeruginosa. *Advances in Bioscience and Biotechnology*, 13, 49–59. https://doi.org/10.4236/abb.2020.111005

Kleerebezem, M., and Vaughan, E. E. (2020). Probiotic health benefits in the context of gut microbiota and bacterial infections. *Microbial Cell Factories*, 8(Suppl 1), S5. https://doi.org/10.1186/s12934-020-01406-0

Ley, R. E., Peterson, D. A., and Gordon, J. I. (2006). Ecological and evolutionary forces shaping microbial diversity in the human gut. *Cell,* 124(4), 837–848. https://doi.org/10.1016/j.cell.2006.02.017

Lozupone, C. A., Stombaugh, J. I., & Gordon, J. I. (2012). Diversity, stability, and resilience of the human gut microbiota. *Nature,* 489(7415), 220–230. https://doi.org/10.1038/nature11550

Mäkelä, K., Forslund, M., and Oksman, S. (2021). Probiotics and gut health: A comprehensive review of their effects. *Journal of Functional Foods*, 80, 104417. https://doi.org/10.1016/j.jff.2021.104417

Makinde, O. M., Ayeni, K. I., Sulyok, M., Krska, R., Adeleke, R. A., and Ezekiel, C. N. (2020). Microbiological safety of ready-to-eat foods in low- and middle-income countries: A comprehensive 10-year (2009–2018) review. *Comprehensive Reviews in Food Science and Food Safety,* 19, 703–732. https://doi.org/10.1111/1541-4337.12529

Mannan, S. J., Rezwan, R., Rahman, M. S., and Begum, K. (2017). Isolation and biochemical characterization of Lactobacillus species from yogurt and cheese samples in Dhaka. *Bangladesh Pharmaceutical Journal*, 20(1), 1–8. https://doi.org/10.3329/bpj.v20i1.31982

Mohammed, S. S. D., Butt, Q. A., Wartu, J. R., and AbdulRahman, A. A. (2024). Production of crude bacteriocins by selected lactic acid bacteria isolated from some fermented foods. *Science World Journal,* 19(2), 554–559. https://doi.org/10.4314/swj.v19i2.35

Morrison, D. J., and Preston, T. (2021). Formation of short-chain fatty acids in the human gut and their impact on health. *Nutrients,* 13(4), 935. https://doi.org/10.3390/nu13040935

O'Sullivan, O., Al-Qudah, M. M. A., Rahahleh, R. J., Alraei, W. Y., Aljaraedah, T. Y., Abu-Harirah, H. A., Amawi, K. F., & El-Qudah, J. M. F. (2023). Evaluation of the antimicrobial activity of bacteriocin-producing lactic acid bacteria isolated from human intestine against pathogenic microorganisms. *Tropical Journal of Natural Product Research*, 7(6), 3182–3190. https://doi.org/10.26538/tjnpr/v7i6.5

Pérez-Burillo, S., Pastoriza, S., and Rufián-Henares, J. Á. (2021). Gut microbiota modulation by probiotics and its impact on human health. *Trends in Food Science & Technology*, 108, 175–185. https://doi.org/10.1016/j.tifs.2020.12.014

Perez, R. H., Zendo, T., and Sonomoto, K. (2023). Bacteriocins: Potentials and applications in food systems. *Microorganisms,* 11(4), 935. https://doi.org/10.3390/microorganisms11040935

Reid, G., Jass, J., and Sebulsky, M. T. (2020). Survival of probiotics in the gastrointestinal environment. *International Journal of Dairy Technology*, 73(3), 496–502. https://doi.org/10.1111/1471-0307.12729

Sorescu, I., Dumitru, M., Hăbeanu, M., and Ciurescu, G. (2020). Lactobacillus spp. strains isolation, identification, preservation and quantitative determinations from the intestinal content and faeces of weaned piglets. *Archiva Zootechnica*, 23, 84–100. https://sciendo.com/article/10.2478/azibna-2020-0015

Tannock, G. W. (2021). The gut microbiota and probiotics in human health. *Annual Review of Microbiology*, 75(1), 291–315. https://doi.org/10.1146/annurev-micro-020518-115443