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Review Article

Review on Microbiology of Cereal-Based Spontaneously Fermented Foods and Beverages

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Abstract

Spontaneously fermented cereal-based foods and beverages are fermented by diverse arrays of microorganisms which play significant roles at different stages of fermentation. The aim of this review is to summarize the scientific data on the microbiology of cereal-based spontaneously fermented foods and beverages. Yeasts are a large group of beneficial bacteria in food fermentation followed by lactic acid bacteria. Molds also play an important role in the production of various foods and non-food products. The possible functions of yeast in the fermentation of carbohydrates are aroma production, stimulation of lactic acid bacteria and degradation of mycotoxin. However, this review results reveal that all yeasts and molds are not beneficial microbes. According to the reports of many researchers, *Enterobacteriaceae* and total coliforms are not persisted to the end of fermentation. However, aerobic mesophilic bacteria, staphylococcus spp., and aerobic spore-forming bacteria are persisted to the end of some fermented food and beverage products. In spontaneous fermentation, aerobic spore-forming bacteria play crucial role in the begging stage of fermentation to breakdown of complex structure of food composition which facilitates the environment for the yeast and lactic acid bacteria. This review concluded that spontaneous fermentation process reduces both pathogenic and spoilage microorganisms to non-significant level thus make the end product safe for consumption.

Keywords

Fermented Foods and Beverage, Microorganisms, Spontaneous Fermentation

1. Introduction

Spontaneously fermented cereal-based foods and beverages are fermented by diverse arrays of microorganisms (Figure 1) such as lactic acid bacteria, yeasts, molds, and different *Bacillus* spp. [1-3]. These different groups of microorganisms play significant roles at different stages of fermentation, thus enhancing their organoleptic and preservative properties while improving their nutritional quality [4, 5].

On the other hand, the establishment of a particular microflora in the substrate depends on water activities, pH, food matrix composition, salt concentration, and method of preparation [2]. During spontaneous fermentation, microbes either occur in succession or co-exist with other microbial groups in a synergistic effect. For example, yeast multiplication is favored by an acidic environment developed due to the metabolic activities of LAB, while bacterial growth is favored by the yeast's activities as it provides several growth factors such as vitamins, minerals, and nitrogen compounds during fermentation [6].

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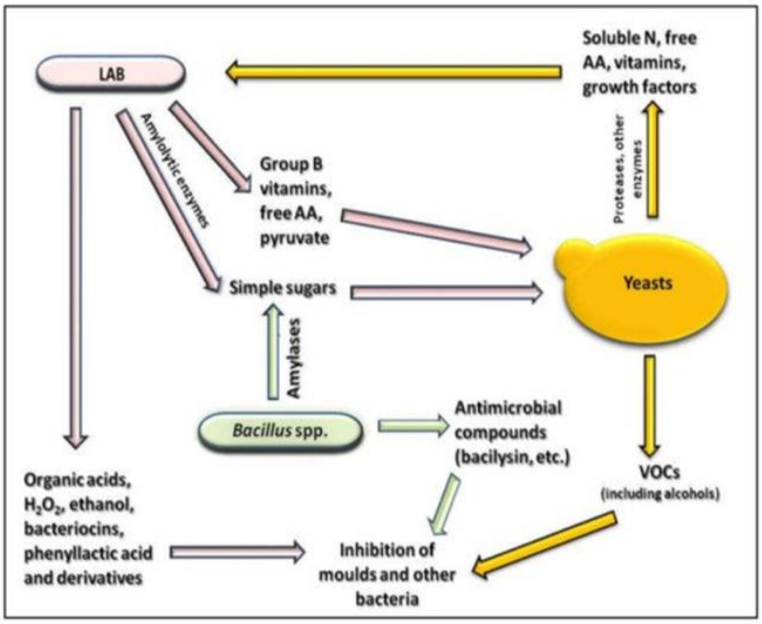

Figure 1. *The interactions among the principal microbial groups during spontaneous fermentation [3].*

2. Microorganisms Participated in Cereal-Based Spontaneous Fermentation

2.1. Lactic Acid Bacteria (LAB)

Lactic acid bacteria are a group of gram-positive, non-respiring, non-spore-forming, non-pigmented, and non-motile cocci or rods that produce lactic acid as the major end product of the fermentation of carbohydrates [7, 8]. They are catalase- and oxidase-negative due to a lack of cytochromes and porphyrins. Some of them are producing hydrogen peroxide, thus destroying pathogenic microorganisms in fermented products [9]. Regarding nutrients requirement during their growth time, they need special nutritional supplements such as amino acids and B-vitamins; therefore, they are categorized as fastidious microorganisms [10].

Lactic acid bacteria (LAB) are a large group of beneficial bacteria in food fermentation for the production of alcoholic and non-alcoholic beverages, porridges, sausage, gruels, snacks, and dairy products [11-16]. During fermentation, LAB improves keeping quality and enhances the palatability of food and beverage products [17-19]. Hu and others [20] reported that the associations of two or three strains of LAB and yeasts during the fermentation of dough contribute metabolites that impart taste and flavor to food products. The strains of LAB are capable of lowering the pH of foods below 4.0. As a result, both spoilage and pathogenic microorganisms are eliminated, making lactic acid bacteria predominant in most fermentation processes [21].

Among LAB, the genera *Lactobacillus* is highly heterogeneous and commonly found in fermented milk, meat, vegetables, and cereals [22, 23]. Among them, *Lactobacillus acidophilus* strains are added to dairy foods due to their physiological benefits [10]. It has been reported that during dough fermentation of maize, *Pediococcus* species and *Lactobacillus brevis* dominate the latter stage of fermentation [24, 25]. Also, the lactic acid bacteria isolated from *Ogi*, *Azo*, and *Borde* were mostly the *Lactobacillus* species [22, 23] which prefer acidic conditions to all other lactic acid bacteria [26, 27]. Olympia and others [28] reported that the strain of *Lactobacillus plantarum* hydrolyses soluble starch, while they do no effect on dextran and cyclodextrins. The breakdown of the starch might be due to the presence of enzymes such as α- and β-galactosidase produced by this strain [29]. Nigatu and other [30] have demonstrated that the genera of lactic acid bacteria such as *Pediococcus*, *Lactobacillus*, *Streptococcus*, and *Leuconostoc* were responsible for the acidic characteristics of dough of teff and Kocho fermentation.

The first biochemical and physiological characterization trial of lactic acid bacteria was carried out in the nineteen century by Orla−Jensen scientists [31]. According to this classification, four genera of lactic acid bacteria such as *Lactobacillus*, *Pediococcus*, *Leucononstoc*, and *Streptococcus* were identified [32]; however, recently lactic acid bacteria were re-classified by scientists into 25 genera [33]. LABs are divided into two distinct phyla according to taxonomical classification: Firmicutes and Actinobacteria. Phylum Firmicutes contains such genera as *Lactobacillus, Lactococcus, Leuconostoc, Oenococcus, Pediococcus, Streptococcus, Enterococcus, Tetragenococcus, Aerococcus, Carnobacterium, Weissella, Alloiococcus, Symbiobacterium*, and *Vagococcus*. While within the Actinobacteria phylum, lactic acid bacteria belong to the *Atopobium* and *Bifidobacterium* genera [34].

The genus *Lactobacillus* is recognized as being phylogenetically highly heterogeneous consisting of over 152 validly described species. They are gram−positive, microaerophilic, and non-flagellated rods or coccobacilli. *Lactobacillus* is present either as pairs or in chains of different lengths. Lactobacilli are known to resist acids and ferment a diversity of food products than other genera of LAB [35, 36]. Based on their carbohydrate fermentation, members of the genus *lactobacillus* are subdivided into three groups: obligate homo-fermentative, facultative hetero-fermentative, and obligate hetero-fermentative.

Lactococcus is a genus of lactic acid bacteria formerly included in the genus *Streptococcus*. The first studies of this genus were made by Lister, [37], as a microorganism responsible for milk fermentation. Morphologically they are ovoid or spherical cells that occur either singly, in pairs, or in chains under a microscope. A *Lactococcus* genus was distinguished from *Streptococcus* and *Enterococcus* by growth at 10℃ but not at 45℃ [38]. They are mostly used in dairy fermentation although some of them are still suitable for cereal fermentations [39].

The name *Streptococcus* was derived from two Greek words 'streptos' meaning easily twisted and 'kokkos' meaning grain which was first used in 1874 by Billroth, [40]. The organism does not grow at 15℃, but most strains can grow between 40℃ and 50℃. *Streptococcus* species could proliferate at low pH following *Lactobacillus* [41]. Many species of this genus are harmful to human beings, but *Streptococcus thermophiles* variant *salivarius* is widely used as a starter in the manufacture of dairy products as they have GRAS (Generally recognized as safe) status [42]. The end products of lactose fermentation by the aforementioned species are lactate, acetaldehyde, and diacetyl which contribute to the flavor and taste of dairy end products [43].

The genera *Pediococcus* is recognized as gram-positive, catalase-negative, oxidase-negative, and homo-fermentative. They grow under facultative aerobic to microaerophilic conditions. The cells are uniformly spherical and they differ from other lactic acid bacteria by alternate division in two perpendicular directions resulting in tetrad formation, though they sometimes occur in pairs and in chains [44]. Members of the genus *Pediococcus* can grow at 45℃; however, the optimum growth temperature is 32℃. Some species of the same genus can grow in salt-concentrated foods like brined vegetables (up to 18% NaCl) [38].

Enterococci are facultatively anaerobic, non-spore-forming, and homo-fermentative cocci that tolerate harsh conditions such as extreme temperature (10-45℃), pH (4.5-10.0), and high sodium chloride concentrations [45]. Enterococcus represents 6% of the fecal microbiota and 23% of the gut microbiota [46]. They play role in ripening and aroma development in fermented foods [47, 48]. Some *Enterococcus* strains have been used as human probiotics, while few strains are important nosocomial pathogens causing bacteremia, endocarditis, and other infections [49].

Members of the genus *Leuconostoc* are mesophilic, diplococci in the oval chain, and hetero-fermentative commonly used as adjunct cultures in the dairy industry [12]. However, they are isolated from different fermented and unfermented foods [44, 50]. They are distinguished from hetero-fermentative *Lactobacillus* by their inability to hydrolyze arginine [38] besides their difference in shape.

2.2. Yeast

Like lactic acid bacteria, yeasts are also responsible for the fermentation of different food products [51-53]. They have a role in the fermentation of cereal-based fermented foods, beverages, and condiments [54-56]. The predominant strains reported from fermented cereals were *Saccharomyces cerevisiae*, *Geotrichum candidum*, *Candida krusei* and *Candida tropicalis* [57]. Yeasts are intimately involved in the production of alcoholic beverages due to their ability to ferment sugar into ethanol efficiently and tolerate ethanol concentrations of 15-20% v/v [58]. The genus *Saccharomyces*, in particular, *Saccharomyces cerevisiae* is strongly associated with the production of fermented cereal products made for human consumption, especially in alcoholic fermentation [7]. Hammes and others [59] reported that *Saccharomyces cerevisiae* is the principal yeast of most bread fermentation which causes expansion and leavening of dough, which ultimately give palatability to bread. *Torulaspora delbrueckii* and *Kluyveromyces thermotolerans* are used to prepare frozen dough bread due to their freeze-tolerant ability than *S. cerevisiae* [60].

The possible functions of yeast in the fermentation of carbohydrates are aroma production, stimulation of lactic acid bacteria, providing essential metabolites, inhibition, and degradation of mycotoxin, and degradation of cyanogenic glucosides [57, 61, 62]. Their strains contribute significantly to the structural quality and organoleptic characteristics of the fermented products [7, 63]. Yeast exhibits a wide range of enzymatic activities that produce flavor compounds such as alcohols, acids, esters terpenes, and lactones during cereal fermentation. Walker and Stewart, [64] reported that *Saccharomyces cerevisiae* produces numerous secondary metabolites which dictate the final flavor and aroma characteristics of beverages. In addition to organoleptic properties, yeasts in cereal fermentation increase the protein content of fermented food products [7, 65].

On the other hand, some species of yeasts are common contaminants of cereal, dairy, meat, and fruit and vegetable products that provide a favorable niche for their growth [66-69]. They are responsible for significant economic losses due to visible and/or invisible defects that lead to significant food losses. In addition, they produce mycotoxins as secondary metabolites that pose health risks to human beings after the consumption of food products [70]. The control of fungal spoilage is a major concern for scientists that are looking for efficient solutions to prevent fungal spoilage and toxicity in fermented foods [66]. Fermentation is one of the robust solutions to mitigate fungal spoilage in cereal crops and eliminate its toxicity [70-72].

2.3. Molds

Molds play an important role in the production of various pigments, foods, beverages, antibiotics, pharmaceuticals, and enzymes [73, 74]. On the other hand, some species of molds cause a negative effect through the biodegradation of natural materials; especially in products with high sugar content and low pH [75]. These include species of Zygomycetes, Penicillium, Aspergillus, Rhizopus, Mucor, Geotrichum, Fusarium, Alternaria, Cladosporium, Eurotium, and Byssochlamys which causes food spoilage and some of them produce toxins [16, 76]. It has been reported that species of Actinomucor, Amylomyces, Aspergillus, Monascus, Mucor, Penicillium, Rhizopus, and Ustilago are found in many fermented foods, Asian non-food amylolytic starters, and alcoholic beverages [77, 78].

2.4. Aerobic Mesophilic Bacteria (AMB)

Aerobic mesophilic bacteria are the total number of bacteria that can grow in an aerobic environment under moderate incubation temperature. They are either gram-positive or gram-negative. Aerobic mesophilic bacteria are indicators of quality providing useful information about the shelf life of storage foods and beverages [79]. In many fermented foods, beverages, and condiments, AMBs are observed at the beginning and even at the final stage of fermentation [54, 27, 56, 80]. However, Anumudu and others [81] reported that members of AMB that started the fermentation did not persist until the end of the fermentation stage during *Ogi* fermentation.

2.5. Enterobacteriaceae

Enterobacteriaceae are gram-negative, facultatively anaerobic, fermentative, mesophilic, non-spore-forming bacteria that include both pathogenic and spoilage bacteria [80]. They are incapable of growth below water activity 0.95. These organisms have the potential to spoil foods [79, 82, 83]. Enterobacteriaceae are strongly affected by high temperature, salt concentration, and low pH. Nevertheless, they secrete acyl homo-serine lactones to regulate proteolytic enzyme production and iron chelation during the spoilage of foods [84]. Some members of Enterobacteriaceae produce off-odors and off-colors in beer and spoil most of the fermented food products [84]. Representative spoilage genera of Enterobacteriaceae include *Escherichia, Erwinia, Enterobacter, Citrobacter, Serratia*, and *Proteus*.

The members of Enterobacteriaceae present in cereal-based fermented foods are *Salmonella* spp., *Enterobacter* spp., *Klebsiella* spp., *E. coli*, and *Shigella* spp. [85-88]. The occurrences of these microbes are due to poor hygienic practices during the processing, handling, transportation, and utilization of contaminated water [89, 90]. Even during fermentation, some of these organisms produce stress responses that facilitate their adaptation to an acidic environment [91-93]. However, many researchers reported that Enterobacteriaceae could not persist until the final stage of food fermentation [54, 88, 94]. This could indicate that tolerance to very stressful environments by members of the family Enterobacteriaceae is minimal and their tolerance fades with concentration and time of exposure.

2.6. Staphylococci

Staphylococci are involved in the spoilage of both fresh produce and processed foods and beverages [76]. It has been reported that the species of staphylococci occur in many different fermented foods and beverages [87, 88, 95]. In some fermented foods, their colony counts are below the threshold at the final stage of fermentation [88, 96]; however, above the threshold in other fermented beverages at the same fermentation stages [54, 97]. One of the most common vehicles for the transmission of these microbes to food and beverage products are the contact between food and human being as they are found on the human skins and some parts of human respiratory organs [98].

2.7. Aerobic Spore-Forming Bacteria (ASFB)

Bacillus species are known to contaminate raw and processed foods [76, 99, 100]. They are often counted as spoilage microorganisms in dairy industries [101]. Among the most important species of the genus Bacillus for food safety concerns is Bacillus cereus. According to the food safety authority of different countries, the borderlines for Bacillus cereus in processed foods are 10^3- $\leq 10^5$ cfu/g [102, 103]. The big problems with these microbes are invisibility of their toxins and spores until there is a foodborne outbreak [104]. On the other hand, species of the genus Bacillus secrete different types of enzymes that could use in spontaneous fermentation to start catabolic activities and facilitate conditions for other microorganisms [105].

2.8. Total Coliform Bacteria (TC)

Total coliforms are a large group of gram-negative, rod-shaped, and thermotolerant microorganisms. They are known to produce acid and gas during the fermentation of lactose. The bacteria encompass thermotolerant and faecal coliforms. The presences of total coliforms in foods are not only faecal contamination but also Citrobacter, Enterobacter, Hafnia, and Klebsiella. However, the presence of faecal streptococci is evidence of faecal contamination. Faecal streptococci are total coliforms those highly resistant to dry environments [106]. Most of the time total coliforms are from contaminated water [106, 107].

3. Conclusion

This review concluded that in spontaneous fermentation as beneficial microorganisms start to produce secondary metabolites both pathogenic and spoilage microorganisms start to eliminate the system. However, not almost all of the pathogenic and spoilage microorganisms eliminate from fermented products. Yeasts stimulate the growth of lactic acid bacteria through providing essential metabolites such as vitamins, while lactic acid bacteria produce organic acids. Thus, most of the spontaneously fermented foods and beverages are dominated by lactic acid bacteria and yeasts.

Abbreviations

AMB	Aerobic Mesophilic Bacteria
ASFB	Aerobic Spore-Forming Bacteria
LAB	Lactic Acid Bacteria
TC	Total Coliform Bacteria

Author Contributions

Daniel Asfaw Kitessa is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Katina, K., Poutanen, K., 2013. Nutritional aspects of cereal fermentation with lactic acid bacteria and yeast, in: Handbook on Sourdough Biotechnology. Springer, Pp. 229–244. https://doi.org/10.1007/978-1-4614-5425-0_9

[2] Banwart GJ. 1979. Basic Food Microbiology. Westport, Conn.: AVI. Chapter 4, Factors that affect microbial growth in food; p 115.

[3] Chaves-López, C., Serio, A., Grande-Tovar, C. D., Cuervo-Mulet, R., Delgado-Ospina, J., Paparella, A., 2014. Traditional fermented foods and beverages from a microbiological and nutritional perspective: the Colombian heritage. *Comprehensive Reviews in Food Science and Food Safety*, 13: 1031–1048. https://doi.org/10.1111/1541-4337.12098

[4] Admassie, M., 2018. A review on food fermentation and the biotechnology of lactic acid bacteria. *World Journal of Food Science and Technology*, 2: 19–24. https://doi.org/10.11648/j.wjfst.20180201.13

[5] Braide, W., Azuwike, C. O., Adeleye, S. A., 2018. The role of microorganisms in the production of some indigenous fermented foods in Nigeria. *International Journal of Advanced Research in Biological Sciences*, 5: 86–94. http://dx.doi.org/10.22192/ijarbs.2018.05.05.011

[6] Preetha, S. S., and Narayanan, R., 2020. Factors Influencing the Development of Microbes in Food. *Shanlax International Journal of Arts, Science and Humanities*, 7(3): 57–77. https://doi.org/10.34293/sijash.v7i3.473

[7] Ukwuru, M. U., Muritala, A., Ukpomwan, S., 2018. Ecology of traditional cereal fermentation. *UPI Journal of Chemical and Life Sciences*, 1(1): 22–36.

[8] Bintsis, T., 2018. Lactic acid bacteria: Their applications in foods. *Journal of Bacteriology and Mycology*, 6(2): 89–94. https://doi.org/10.15406/jbmoa.2018.06.00182

[9] Kang, D-K., Oh, K. K., Ham J-S., Kim, J. G. Yoon, C. H. Ahn, Y. T., Kim, H. U., 2005. Identification and Characterization of Hydrogen Peroxide-generating Lactobacillus fermentum CS12-1. *Asian-Australasian Journal of Animal Sciences*, 18(1): 90-95. https://doi.org/10.5713/ajas.2005.90

[10] Liptáková, D., Matejčeková, Z., Valík, L., 2017. Lactic acid bacteria and fermentation of cereals and pseudocereals. Chapter from the Book Fermentation Processes, Published by INTECH, Pp 124-142. https://doi.org/10.5772/65459

[11] Bacha, K., Mchari, T., Ashenafi, M., 1999. Microbiology of the fermentation of shamita, a traditional Ethiopian fermented beverage. *SINET: Ethiopian Journal of Science*, 22: 113–126. https://doi.org/10.4314/sinet.v22i1.18137

[12] Liu, S.-Q., Holland, R., Crow, V. L., 2003. The potential of dairy lactic acid bacteria to metabolise amino acids via non-transaminating reactions and endogenous transamination. *International Journal of Food Microbiology*, 86: 257–269. https://doi.org/10.1016/s0168-1605(03)00040-0

[13] Bacha, K., Jonsson, H., Ashenafi, M., 2010. Microbial dynamics during the fermentation of wakalim, a traditional Ethiopian fermented sausage. *Journal of Food Quality*, 33: 370–390. https://doi.org/10.1111/j.1745-4557.2010.00326.x

[14] Nwachukwu, E., Achi, O. K., Ijeoma, I. O., 2010. Lactic acid bacteria in fermentation of cereals for the production of indigenous Nigerian foods. *African Journal of Food Science and Technology*, 1(2): 021–026.

[15] Tamang, J. P., 2010. Diversity of fermented beverages and alcoholic drinks. Fermented Foods and Beverages of the World. Pp 85–125. https://doi.org/10.1201/EBK1420094954-c3

[16] Omemu, A. M., Omeike, S. O., 2010. Microbiological hazard and critical control points identification during household preparation of cooked ogi used as weaning food. *International Food Research Journal*, 17: 257–266.

[17] Rhee, S. J., Lee, J.-E., Lee, C.-H., 2011. Importance of lactic acid bacteria in Asian fermented foods, in: Microbial Cell Factories. BioMed Central, Pp. 1–13. https://doi.org/10.1186/1475-2859-10-S1-S5

[18] Ogunsakin, O. A., Banwo, K., Ogunremi, O. R., Sanni, A. I., 2015. Microbiological and physico-chemical properties of sourdough bread from sorghum flour. *International Food Research Journal*, 22(6): 2610–2618.

[19] Adebo, O. A., Gabriela Medina-Meza, I., 2020. Impact of fermentation on the phenolic compounds and antioxidant activity of whole cereal grains: A mini review. *Molecules*, 25: 1–19. https://doi.org/10.3390/molecules25040927

[20] Hu, Y., Zhang, J., Wang, S., 2022. Lactic acid bacteria synergistic fermentation affects the flavor and texture of bread. *Journal of Food Science*, 87(3): 16082. https://doi.org/10.1111/1750-3841.16082

[21] Savadogo, A., 2012. The role of fermentation in the elimination of harmful components present in Food raw Materials. https://www.researchgate.net/publication/264971133

[22] Kivanc, M., Yilmaz, M., Çakir, E., 2011. Isolation and identification of lactic acid bacteria from boza, and their microbial activity against several reporter strains. *Turkish Journal of Biology*, 35: 313–324. https://doi.org/10.3906/biy-0906-67

[23] Omemu, A. M., Okafor, U. I., Obadina, A. O., Bankole, M. O., Adeyeye, S. A. O., 2018. Microbiological assessment of maize ogi cofermented with pigeon pea. *Food Science and Nutrition*, 6: 1238–1253. https://doi.org/10.1002/fsn3.651

[24] Corsetti, A., Lavermicocca, P., Morea, M., Baruzzi, F., Tosti, N., Gobbetti, M., 2001. Phenotypic and molecular identification and clustering of lactic acid bacteria and yeasts from wheat (species Triticum durum and Triticum aestivum) sourdoughs of Southern Italy. *International journal of food microbiology*, 64: 95–104.

[25] Owusu-Kwarteng, J., Tano-Debrah, K., Glover, R. L. K., Akabanda, F., 2010. Process characteristics and microbiology of fura produced in Ghana. *Nature and Science*, 8: 41–51.

[26] Nsofor, C. A., Ume, S. C., Uzor, B. C., 2014. Isolation and characterization of lactic acid bacteria from ogi sold in Elele, Nigeria. *Journal of Biological and Food Science Research*, 3: 19–22.

[27] Nwokoro, O., Chukwu, B. C., 2012. Studies on Akamu; a traditional fermented maize food. *Revista Chilena de Nutrición*, 39: 180–184.

[28] Olympia, M., Fukuda, H., Ono, H., Kaneko, Y., Takano, M., 1995. Characterization of starch-hydrolyzing lactic acid bacteria isolated from a fermented fish and rice food,"Burong Isda", and its amylolytic enzyme. *Journal of Fermentation and Bioengineering*, 80: 124–130.

[29] Ziarno, M., Cichońska, P., 2021. Lactic acid bacteria-fermentable cereal and pseudocereal-based beverages. *Microorganisms*, 9: 1–16.

[30] Nigatu, A., Gashe, B. A., Ayele, T., 1997. Bacillus spp from fermented tef dough and kocho: identity and role in two Ethiopian fermented foods. *SINET: Ethiopian Journal of Science*, 20: 101–114.

[31] Ayivi, R. D., Gyawali, R., Krastanov, A., Aljaloud, S. O., Worku, M., Tahergorabi, R., Silva, R. C. da, Ibrahim, S. A., 2020. Lactic acid bacteria: Food safety and human health applications. *Dairy*, 1: 202–232.

[32] Wood, B. J., Holzapfel, W. H. N., 1992. The genera of lactic acid bacteria. Springer Science and Business Media, Blackie Academic and Professional, London.

[33] Zheng, J., Wittouck, S., Salvetti, E., Franz, C. M., Harris, H. M., Mattarelli, P., O'toole, P. W., Pot, B., Vandamme, P., Walter, J., 2020. A taxonomic note on the genus Lactobacillus: Description of 23 novel genera, emended description of the genus Lactobacillus Beijerinck 1901, and union of Lactobacillaceae and Leuconostocaceae. *International Journal of Systematic and Evolutionary Microbiology*, 70: 2782–2858.

[34] Ludwig, W., Schleifer, KH., Whitman W. B., 2011. Revised Road Map to the Phylum Firmicutes. Book Chapter, Systematic Bacteriology, 1-13. https://doi.org/10.1007/978-0-387-68489-5_1

[35] Gomes, A. M., Malcata, F. X., 1999. Bifidobacterium spp. and Lactobacillus acidophilus: biological, biochemical, technological and therapeutical properties relevant for use as probiotics. *Trends in Food Science and Technology*, 10: 139–157.

[36] Goyal, R., Dhingra, H., Bajpai, P., Joshi, N., 2012. Characterization of the Lactobacillus isolated from different curd samples. *African Journal of Biotechnology*, 11: 14448–14452.

[37] Lister, J., 1873. Memoirs: A Further Contribution to the Natural History of Bacteria and the Germ Theory of the Fermentative Changes. *Journal of Cell Science*, 2: 380–408. https://doi.org/10.1016/s0168-1605(00)00447-5

[38] Adams, M., Moss, M., 2000. Food Microbiology. 2nd Edition. The Royal Society of Chemistry, London.

[39] Matejčeková, Z., Liptáková, D., Valík, L., 2015. Fermentation of milk-and water-based amaranth mashes. *Acta Chimica Slovaca*, 8: 140–145.

[40] Billroth, T., 1874. Untersuchungen über die Vegetationsformen von Coccobacteria septica und den Antheil, welchen sie an der Entstehung und Verbreitung der accidentellen Wundkrankheiten haben: Versuch einer wissenschaftlichen Kritik der verschiedenen Methoden antiseptischer Wundbehandlung. G. Reimer.

[41] Almuzara, M. L., Bonofiglio, R., Cittadini, C., Vera Ocampo, A., Montilla, M., Del Castillo, M., S., Ramirez, M., Mollerach., Vay, C., 2013. First case of Streptococcus lutetiensis bacteremia involving a clindamycin-resistant isolate carrying the lnuB gene. *Journal of Clinical Microbiology*, 51: 4259–4261. https://doi.org/10.1128/JCM.01774-13

[42] Delorme, C., 2008. Safety assessment of dairy microorganisms: Streptococcus thermophilus. *International Journal of Food Microbiology*, 126: 274–277. https://doi.org/10.1016/j.ijfoodmicro.2007.08.014

[43] Dan, T., Ren, W., Liu, Y., Tian, J., Chen, H., Li, T., Liu, W., 2019. Volatile flavor compounds profile and fermentation characteristics of milk fermented by Lactobacillus delbrueckii subsp. bulgaricus. *Frontiers in Microbiology*, 10: 1–10. https://doi.org/10.3389/fmicb.2019.02183

[44] Franz, C. M., Vancanneyt, M., Vandemeulebroecke, K., De Wachter, M., Cleenwerck, I., Hoste, B., Schillinger, U., Holzapfel, W. H., Swings, J., 2006. Pediococcus stilesii sp. nov., isolated from maize grains. *International Journal of Systematic and Evolutionary Microbiology*, 56: 329–333. https://doi.org/10.1099/ijs.0.63944-0

[45] Manero, A., Blanch, A. R., 1999. Identification of Enterococcus spp. with a Biochemical Key. *Applied and Environmental Microbiology*, 65(10): 4425–4430. https://doi.org/10.1128/aem.65.10.4425-4430.1999

[46] Pavan, S., Pot, B., 2003. A simple method for semi-preparative-scale production and recovery of enterocin AS-48 derived from Enterococcus faecalis subsp. liquefaciens A-4 Curr. Pharm. Des. 9: 175–191. https://doi.org/10.1016/s0167-7012(03)00202-1

[47] Franz, C. M., Stiles, M. E., Schleifer, K. H., Holzapfel, W. H., 2003. Enterococci in foods: A conundrum for food safety. *International Journal of Food Microbiology*, 88: 105–12210. https://doi.org/1016/s0168-1605(03)00174-0

[48] Olatunde, O. O., Obadina, A. O., Omemu, A. M., Oyewole, O. B., Olugbile, A., Olukomaiya, O. O., 2018. Screening and molecular identification of potential probiotic lactic acid bacteria in effluents generated during ogi production. *Annals of Microbiology*, 68; 433–443. https://doi.org/10.1007/s13213-018-1348-9

[49] Lukjancenko, O., Ussery, D. W., Wassenaar, T. M., 2012. Comparative genomics of Bifidobacterium, Lactobacillus and related probiotic genera. *Microbial Ecology*, 63: 651–673. https://doi.org/10.1007/s00248-011-9948-y

[50] De Bruyne, K., Schillinger, U., Caroline, L., Boehringer, B., Cleenwerck, I., Vancanneyt, M., De Vuyst, L., Franz, C. M., Vandamme, P., 2007. Leuconostoc holzapfelii sp. nov., isolated from Ethiopian coffee fermentation and assessment of sequence analysis of housekeeping genes for delineation of Leuconostoc species. *International Journal of Systematic and Evolutionary Microbiology*, 57: 2952–2959. https://doi.org/10.1099/ijs.0.65292-0.

[51] Watanabe, K., Fujimoto, J., Sasamoto, M., Dugersuren, J., Tumursuh, T., Demberel, S., 2008. Diversity of lactic acid bacteria and yeasts in Airag and Tarag, traditional fermented milk products of Mongolia. *World Journal of Microbiology and Biotechnology*, 24: 1313–1325. https://doi.org/10.1007/s11274-007-9604-3

[52] Tamang, J. P., Fleet, G. H., 2009. Yeasts diversity in fermented foods and beverages: Yeast Biotechnology: Diversity and Applications. Springer, Pp. 169–198. https://doi.org/10.1007/978-1-4020-8292-4_9

[53] Lv, X.-C., Huang, X.-L., Zhang, W., Rao, P.-F., Ni, L., 2013. Yeast diversity of traditional alcohol fermentation starters for Hong Qu glutinous rice wine brewing, revealed by culture-dependent and culture-independent methods. *Food Control*, 34: 183–190. https://doi.org/10.1016/j.foodcont.2013.04.020

[54] Bacha, K., Mchari, T., Ashenafi, M., 1998. The microbial dynamics of 'borde' fermentation, a traditional Ethiopian fermented beverage. *SINET: Ethiopian Journal of Science*, 21: 195–205.

[55] Satyanarayana, T., Kunze, G., 2009. Yeast biotechnology: diversity and applications. Springer.

[56] Gebrelibanos, L., 2015. Microbiological and physiochemical study of azo; a traditional fermented condiment prepared from sorghum and leaves of endod (Phytolacca dodecandra). MSc. Thesis in microbiology, Addis Ababa University, Ethiopia.

[57] Omemu, A. M., Oyewole, O. B., Bankole, M. O., 2007. Significance of yeasts in the fermentation of maize for ogi production. *Food microbiology*, 24: 571–576. https://doi.org/10.1016/j.fm.2007.01.006

[58] Lea, A. G., Piggott, J. R., 2003. Fermented beverage production. Andrew G. H. Lea, John R. Piggott Editors of the book. Springer Science and Business Media.

[59] Hammes, W. P., Brandt, M. J., Francis, K. L., Rosenheim, U. J., Seitter, F. H. and Vogelmann, A. 2005. Microbial Ecology of Cereal Fermentations. *Trends in Food Science and Technology*, 16: 4–11. https://doi.org/10.1016/j.tifs.2004.02.010

[60] Alves-Araújo, C., Almeida, M. J., Sousa, M. J., Leão, C., 2004. Freeze tolerance of the yeast Torulaspora delbrueckii: Cellular and biochemical basis. *FEMS microbiology letters*, 240: 7–14. https://doi.org/10.1016/j.femsle.2004.09.008

[61] Fredlund, E., Druvefors, U. Ä., Olstorpe, M. N., Passoth, V., Schnürer, J., 2004. Influence of ethyl acetate production and ploidy on the anti-mold activity of Pichia anomala. *FEMS Microbiology Letters*, 238: 133–137. https://doi.org/10.1111/j.1574-6968.2004.tb09747.x

[62] Ponomarova, O., Gabrielli, N., Sévin, D. C., Mülleder, M., Zirngibl, K., Bulyha, K., Andrejev, S., Kafkia, E., Typas, A., Sauer, U., 2017. Yeast creates a niche for symbiotic lactic acid bacteria through nitrogen overflow. *Cell Systems*, 5: 345–357. https://doi.org/10.1016/j.cels.2017.09.002

[63] Karovičová, Z. K.-J., Kohajdova, J., 2007. Fermentation of cereals for specific purpose. *Journal of Food and Nutrition Research*, 46: 51–57.

[64] Walker, G. M., Stewart, G. G., 2016. Saccharomyces cerevisiae in the production of fermented beverages. *Beverages*, 2: 1–11. https://doi.org/10.3390/beverages2040030

[65] Svanberg, U., Lorri, W., 1997. Fermentation and nutrient availability. *Food Control*, 8: 319–327.

[66] Magan, N., Aldred, D., 2007. Post-harvest control strategies: Minimizing mycotoxins in the food chain. *International Journal of Food Microbiology*, 119: 131–139. https://doi.org/10.1016/j.ijfoodmicro.2007.07.034

[67] Garnier, L., Valence, F., Pawtowski, A., Auhustsinava-Galerne, L., Frotté, N., Baroncelli, R., Deniel, F., Coton, E., Mounier, J., 2017. Diversity of spoilage fungi associated with various French dairy products. *International Journal of Food Microbiology*, 241: 191–197. https://doi.org/10.1016/j.ijfoodmicro.2016.10.026

[68] Saleh, I., Al-Thani, R., 2019. Fungal food spoilage of supermarkets' displayed fruits. *Veterinary World*, 12(11): 1877–1883.

[69] Nair, A. T., 2021. Bioaerosols in the landfill environment: An overview of microbial diversity and potential health hazards. *Aerobiologia*, 37: 185–203.

[70] Adebo, O. A., 2020. African sorghum-based fermented foods: Past, current and future prospects. *Nutrients*, 12: 1–25. https://doi.org/10.3390/nu12041111

[71] Satish Kumar, R., Kanmani, P., Yuvaraj, N., Paari, K. A., Pattukumar, V., Arul, V., 2013. Traditional Indian fermented foods: A rich source of lactic acid bacteria. *International Journal of Food Sciences and Nutrition*, 64: 415–428. https://doi.org/10.3109/09637486.2012.746288

[72] Hasan, M. N., Sultan, M. Z., Mar-E-Um, M., 2014. Significance of fermented food in nutrition and food science. *Journal of Scientific Research*, 6: 373–386. https://doi.org/10.3329/jsr.v6i2.16530

[73] Aidoo, K. E., Nout, M. R., 2010. Functional yeasts and molds in fermented foods and beverages. *Fermented Foods and Beverages of the World*, 127–148. https://doi.org/10.1201/EBK1420094954-c4

[74] Toma, M. A., Nazir, K. N. H., Mahmud, M. M., Mishra, P., Ali, M. K., Kabir, A., Shahid, M. A. H., Siddique, M. P., Alim, M. A., 2021. Isolation and Identification of Natural Colorant Producing Soil-Borne Aspergillus Niger from Bangladesh and Extraction of the Pigment. *Foods*, 10: 1–11. https://doi.org/10.3390/foods10061280

[75] Filtenborg, O., Frisvad, J. C., Thrane, U., 1996. Molds in food spoilage. *International Journal of Food Microbiology*, 33: 85–102. https://doi.org/10.1016/0168-1605(96)01153-1

[76] Cook, F. K., Johnson, B. L., 2009. Microbiological spoilage of cereal products, in: Compendium of the Microbiological Spoilage of Foods and Beverages. Springer, Pp. 22 3–244. https://doi.org/10.1007/978-1-4419-0826-1_8

[77] Nout, M. J., Aidoo, K. E., 2011. Asian fungal fermented food: Industrial Applications. Springer, Pp. 29–58.

[78] Chen, B., Wu, Q., Xu, Y., 2014. Filamentous fungal diversity and community structure associated with the solid state fermentation of Chinese Maotai-flavor liquor. *International Journal of Food Microbiology*, 179: 80–84. https://doi.org/10.1016/j.ijfoodmicro.2014.03.011

[79] Centre for Food Safety (CFS), 2014. Microbiological guidelines for food: Ready-to-eat food in general and specific food items; Centre for food safety, food and environmental hygiene department: Hong Kong, China, Pp 1–38.

[80] Abawari, R. A., 2013. Microbiology of keribo fermentation: An Ethiopian traditional fermented beverage. *Pakistan Journal of Biological Sciences*, 16: 1113–1121. https://doi.org/10.3923/pjbs.2013.1113.1121

[81] Anumudu, C. K., Omeje, F. I., Obinwa, G. N., 2018. Microbial succession pattern in Ogi fermentation. *International Journal of Advanced Research in Biological Sciences*, 5: 247–251. http://dx.doi.org/10.22192/ijarbs.2018.05.07.019

[82] Doyle, M. E., 2007. Microbial Food Spoilage: Losses and Control Strategies. A Brief Review of the Literature. *FriBriefings*, 1-10.

[83] Teferi, S. C., 2020. Street food safety, types and microbiological quality in Ethiopia: A Critical review. *American Journal of Applied Scientific Research*, 6: 67–71. https://doi.org/10.11648/j.ajasr.20200603.12

[84] Rasch, M., Andersen, J. B., Nielsen, K. F., Flodgaard, L. R., Christensen, H., Givskov, M., Gram, L., 2005. Involvement of bacterial quorum-sensing signals in spoilage of bean sprouts. *Applied and Environmental Microbiology*, 71: 3321–3330. https://doi.org/10.1128/AEM.71.6.3321-3330.2005

[85] Imoukhuede, T. P., Adepeju, A. B., Akinsuroju, M. O., 2018. Microbiological Quality of Kunnu-Zaki Drinks Sold in Some selected Towns in Osun State, Nigeria. *International Journal of Environment, Agriculture and Biotechnology*, 3: 1308–1315. http://dx.doi.org/10.22161/ijeab/3.4.23

[86] Ogodo, A. C., Ugbogu, O. C., Agwaranze, D. I., Ihiabe, F. U., 2017. Some studies on the bacteriological quality of sorghum-based commercially prepared fermented Ogi (Akamu) in Wukari, Nigeria. *American Journal of Food Science and Nutrition*, 4: 48–51.

[87] Yusuf, A. B., Gulumbe, B. H., Kalgo, Z. M., Aliyu, B., Haruna, M., 2020. Microorganisms associated with the production of burukutu (an alcoholic beverage) in Kebbi State, Nigeria. *Equity Journal of Science and Technology*, 67–73.

[88] Nemo, R., Bacha, K., 2021. Microbial dynamic and growth potential of selected pathogens in Ethiopian traditional fermented beverages. *Annals of Microbiology*, 71: 1–12. https://doi.org/10.1186/s13213-021-01635-7

[89] Adams, M. R., Moss, M. O., McClure, P., 1995. Food Microbiology Royal Society of chemistry. Science Park, Cambridge. Pp 121–122.

[90] Ehiri, J. E., Azubuike, M. C., Ubbaonu, C. N., Anyanwu, E. C., Ibe, K. M., Ogbonna, M. O., 2001. Critical control points of complementary food preparation and handling in eastern Nigeria. *Bulletin of the World Health Organization*, 79: 423–433.

[91] Chauret, C., 2011. Survival and control of Escherichia coli O157: H7 in foods, beverages, soil and water. *Virulence*, 2: 593–601. https://doi.org/10.4161/viru.2.6.18423

[92] Lund, P., Tramonti, A., De Biase, D., 2014. Coping with low pH: molecular strategies in neutralophilic bacteria. *FEMS Microbiology Reviews*, 38: 1091–1125. https://doi.org/10.1111/1574-6976.12076

[93] Vivijs, B., Aertsen, A., Michiels, C. W., 2016. Identification of genes required for growth of Escherichia coli MG1655 at moderately low pH. *Frontiers in microbiology*, 7: 1–12. https://doi.org/10.3389/fmicb.2016.01672

[94] KH, S., 1996. Handbook of Indigenous Fermented Foods Revised and Enlarged. Published by CRC Press. https://doi.org/10.1201/9780203752821

[95] Nemo, R., Bacha, K., 2020. Microbial, physico-chemical and proximate analysis of selected Ethiopian traditional fermented beverages. *LWT Food Science and Technolgy*, 131: 1–6. https://doi.org/10.1016/j.lwt.2020.109713

[96] Food Standards Australia New Zealand (FSANZ), 2016. Compendium of microbiological criteria for food; Food Standards Australia New Zealand, the Terrace: Wellington, New Zealand, Pp. 1–51.

[97] Ogodo, A. C., Agwaranze, D. I., Onudibia, M. E., AwacheI, A. L., 2008. Study on the bacteriological quality of fura sold in Wukari, North-East Nigeria. *Journal of Food Microbiology*, 2: 24–29.

[98] Monica, C., 2006. District laboratory practice in tropical countries.

[99] Ledenbach, L. H., Marshall, R. T., 2009. Microbiological spoilage of dairy products, in: Compendium of the Microbiological Spoilage of Foods and Beverages. Springer, Pp. 41–67.

[100] Buehner, K. P., Anand, S., Djira, G. D., 2015. Prevalence of thermoduric bacteria and spores in nonfat dry milk powders of Midwest origin. *Journal of Dairy Science*, 98: 2861–2866. https://doi.org/10.3168/jds.2014-8822

[101] Gopal, N., Hill, C., Ross, P. R., Beresford, T. P., Fenelon, M. A., Cotter, P. D., 2015. The prevalence and control of Bacillus and related spore-forming bacteria in the dairy industry. *Frontiers in Microbiology*, 6: 1–12. https://doi.org/10.3389/fmicb.2015.01418

[102] Health Protection Agency (HPA), 2009. Guidelines for Assessing the Microbiological Safety of Ready-to-Eat Foods; Health Protection Agency: London, UK, pp. 8–10.

[103] Food Safety Authority of Ireland (FSAI), 2020. Guidelines for the Interpretation of results of microbiological testing of ready-to-eat foods placed on the market; Revision 4; Guidance Note; European Comission: Brussels, Belgium.

[104] Rawat, S., 2015. Food Spoilage: Microorganisms and their prevention. *Asian Journal of Plant Science and Research*, 5: 47–56.

[105] Almeida, E. G., Rachid, C. C., Schwan, R. F., 2007. Microbial population present in fermented beverage 'cauim'produced by Brazilian Amerindians. *International journal of food microbiology*, 120: 146–151. https://doi.org/10.1016/j.ijfoodmicro.2007.06.020

[106] Bartram., J and Ballance, R., 1996. Water Quality Monitoring – A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. 1st edition Book, London. https://doi.org/10.4324/9780203476796

[107] Dwight, R. H., Baker, D. B., Semenza, J. C., Olson, B. H., 2004. Health effects associated with recreational coastal water use: urban versus rural California. *American Journal of Public Health*, 94: 565–567. https://doi.org/10.2105/ajph.94.4.565