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Traditional Brazilian fermented foods: cultural and technological aspects

Thamylles Thuany Mayrink Lima, Bianca de Oliveira Hosken, Bárbara Côgo Venturim, Isabelle Lima Lopes and José Guilherme Prado Martin*

Abstract

Fermented foods production started thousands of years ago and comprised a wide variety of products from different cultures and countries. The discovery of fermented foods is considered an empirical process based on human observation and experimentation of food types susceptible to natural biochemical and microbiological effects. Given the historical miscegenation of Brazilian people, the country has rich cultural diversity and a complex mix of ethnicities, religions and culinary traditions, among others. Thus, the current review aims at presenting the main cultural, microbiological and technological aspects of different types of fermented foods and beverages produced and consumed in Brazil, such as traditional artisanal cheeses, fermented meat (*socol* and *charqui*), non-alcoholic or low-alcohol beverages (*aluá, calugi, tarubá* and *yakupá*), alcoholic beverages (*cachaça, tiquira, caiçuma, cauim* and *caxiri*) and fermented foods based on cassava (*puba, farinha d'água, polvilho azedo* and *tucupi*).

Keywords: Artisanal cheeses, Fermented beverages, Indigenous food, Traditional food

Introduction

Fermented foods production began thousands of years ago and comprised a wide variety of products from different cultures and countries. The fermentation technique accounts for increasing products' shelf life, for diversifying their sensory features, as well as for increasing the bioavailability of bioactive compounds and for nutritional enhancement. Research on fermented food has gained increasing prominence in recent years, mainly to explain the mechanisms involved in health promotion, which are widely associated with fermented food intake [83].

Improvements in fermentation processes enabled techniques and knowledge about them to be transferred from generation-to-generation overtime, contributing to the cultural heritage of different communities abroad [59]. Besides culture and geographic influences, climate conditions, economic factors, raw material availability and endogenous microbiota also affect the development of new fermented food types [112].

Brazil is a South American country with large territorial extension; it presents different climate zones, mostly of the tropical and equatorial types. Given the historical miscegenation of its people, the country has rich cultural diversity, as well as complex mix of ethnicities, religions, culinary traditions, among others, which were influenced by native indigenous peoples, as well as by African and Portuguese peoples [84]. Then, the range of Brazilian fermented foods is associated with such a variety of cultures, since indigenous products based on cassava share room with fermented products introduced in the country by slaved Africans, colonizers or foreign cultures.

One of the recent concerns related to food production comprises the sustainability. The manufacturing of food with nutritional quality must be associated with minimal environmental impacts, as well as promoting the economic and social development. In this context, food production through biotechnology is expected to grow by at least 50% by 2030, impacting the generation of

*Correspondence: guilherme.martin@ufv.br

Microbiology of Fermented Products Laboratory (FERMICRO), Department of Microbiology, Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil

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novel products and the preservation of traditional foods and beverages [70]. Thus, production strategies based on microbial fermentation stand out, resulting in innovative products capable of overcoming global challenges related to the sustainability [23]. In Brazil, several fermented foods – especially *socol,* artisanal cheeses and *cachaça* – are still produced primarily on small and medium-sized family farms or companies. In addition, the production of some fermented foods by indigenous communities includes the use of practically all the raw material, with minimal amounts of waste generated, such as those products based on cassava. Therefore, it is in line with the Sustainable Development Goals (SDGs) from United Nations related to sustainable food production systems, sustainable consumption and economic growth, among others [114].

To the best of our knowledge, the literature does not present another article mainly focused on Brazilian fermented foods. The current review aims at presenting the main features about technological, microbiological and cultural aspects related to traditional fermented foods produced in Brazil, such as artisanal cheeses, fermented meat (*socol* and *charqui*), non-alcoholic or low-alcohol beverages (*aluá, calugi, tarubá* and *yakupá*), alcoholic beverages (*cachaça, tiquira, caiçuma, cauim* and *caxiri*) and fermented foods based on cassava (*puba, farinha d'água, polvilho azedo* and *tucupi*).

Brazilian fermented foods types

The fermented foods produced in Brazil are summarized in Fig. 1. In the following sections, the most common fermented foods produced in the country will be presented; for this, they were classified according to the type of raw material used in their production process.

Fermented foods of animal origin

Artisanal cheeses

Artisanal cheeses stand out among the large diversity of Brazilian cheese types (Fig. 2), given their historical, socioeconomic and cultural importance [88]. Minas Gerais State stands out among the main cheese producing regions, it accounts for 50% of the national production [116]. Artisanal Minas Cheese (AMC) types are produced in the state, which has different micro-regions traditionally featured and acknowledged as producers (Fig. 2A). One of the most striking features of them lies on using an endogenous fermentum deriving from whey of the previous day's production, which is popularly known as "pingo" and whose microbiota contributes to the safety and quality of the cheese.

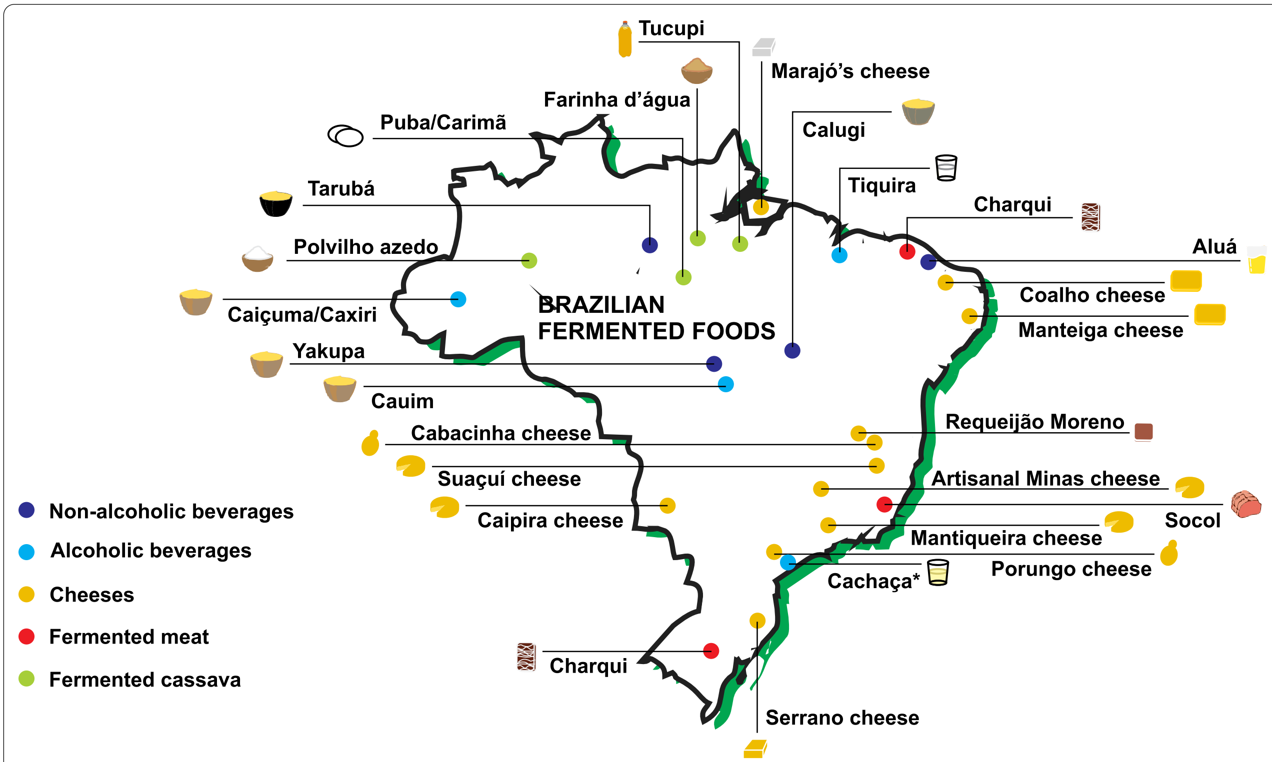

Fig. 1 Fermented food types and beverages representative of Brazilian regions. * The origin of *cachaça* (distilled alcoholic fermented beverage based on sugarcane) remains uncertain, since different versions show that its production started in Pernambuco, Bahia or São Paulo State

Fig. 2 Artisanal cheeses from Brazil: **A** AMC from *Canastra* region undergoing the ripening process; **B** *Canastra* with molds in surface; **C** *Alagoa*; **D** *Porungo*; **E** *Requeijão Moreno*; **F** *Coalho*; **G** *Serrano*

Lactic acid bacteria (LAB) are the most abundant microorganisms found in AMC [56]. *Lactobacillus* sp., *Lacticaseibacillus casei*, *Lactiplantibacillus plantarum*, *Levilactobacillus brevis*, *Enterococcus* sp., *Lactococcus* sp., *Pediococcus* sp., *Leuconostoc mesenteroides and Streptococcus* sp. have been identified by several studies [53], [91]; [74], [20]; [57]. The role of LAB in acidification, safety and sensorial aspects of the product has been demonstrated [56, 57]. Recently, some cheesemakers have been aiming at meeting the increasing demand for surface mold–ripened cheeses with peculiar features (Fig. 2B). *Penicillium* sp., *Aspergillus* sp., *Mucor* sp., *Fusarium* sp., *Trichothecium roseum, Geotrichum candidum, Debaryomyces* spp., *Yarrowia lipolytica, Candida zeylanoides, Kluyveromyces lactis, Trichosporon* spp. stand out among the main isolated fungi species [25, 102, 111]. *Debaryomyces hansenii, G. candidum, Y. lipolytica, C. zeylanoides* and *K. lactis* were related to the production of several volatile compounds relevant for sensorial characteristics of Minas Artisanal Cheeses [111].

Vale do Suaçuí, Mantiqueira and *Cabacinha* cheese types are also produced in Minas Gerais State. Cheeses produced in Vale do Suaçuí (Suaçuí Valley) region and some deriving from Mantiqueira Forest are popularly known as “artisanal parmesan type” (IMA, 2014). The production is mainly concentrated in Alagoa, which is the city where the Artisanal Alagoa Cheese is produced (Fig. 2C). Until now, there is no information about the microbiota of these types of cheese. *Cabacinha* cheese can be considered as a Brazilian version of the Italian Caciocavallo. It is a pasta filata cheese molded in gourd-like shape (*cabaça,* in Portuguese), tied in pairs with strings and kept hanging for natural drying. Its production process involves milk filtering; rennet addition; curd coagulation, cutting, mixing, heating and stirring; syneresis; curd fermentation, stretching, manual drawing, salting in brine and drying [44].

Porungo (Fig. 2D) is a traditional pasta filata cheese produced in Southwest São Paulo State, whose shape and production steps are similar to *cabacinha* cheese. The sales of this product are of great economic importance, as well as income source for countless small producers. These cheeses are formally sold in supermarkets and informally sold directly to consumers or in open markets [75]. LAB present in raw milk and endogenous ferment used in *porungo* cheese production contribute to curd acidification, technological and sensorial quality, in addition to increase its shelf life and safety [24].

Requeijão moreno (Fig. 2E) (also known as *requeijão do Norte*) is an artisanal melted curd cheese mainly produced in Mucuri and Jequitinhonha Valleys, Northeastern Minas Gerais State. Its production includes the milk coagulation by the autochthonous microbiota and subsequent removal of the cream. The curd obtained is cooked at low temperatures and milk is added during the process until it reaches the desired consistency. Afterward, the previously removed cream is cooked at high temperatures until it acquires a brown color, resulting from the Maillard reaction (*moreno* in Portuguese means brown). At the end, both are mixed, cooked again, salted and shaped [107]. Besides being produced in Minas Gerais State, *requeijão moreno* is also found in Goiás State. At this moment, there are no information about its microbiota.

Marajó's cheese is produced in Marajó Island, which is located in Pará State, far Northern Brazil; the region has the largest buffalo herd in the country [98]. *Marajó's* cheese is made from raw buffalo milk (including up to 40% of cow milk) by spontaneous fermentation. After syneresis, the curd is washed twice with water at 70 °C for 15 min and once with milk at 80 °C for 20 min; then, the curd is added with cream or butter [41], [105]. After a pressing step, the curd is cooked at 80 °C until it acquires a homogeneous texture [2]. Therefore, two *Marajó's* cheese varieties are available in the market: cream and butter types; they differ from each other in fat levels and moisture. When cream is added, a product with approximately 50% of moisture and 22% of fat on dry extract (FDE) is obtained. When butter is added, 35% of moisture and 42% of FDE are observed [34, 42]. *Weissella* sp., *Streptococcus* sp., *Lactococcus* sp., *Leuconostoc* sp., *Pediococcus* sp., *Lactobacillus* sp. and *Enterococcus* sp. have been identified in both varieties; this microbiota plays an important role in the acidification process, diacetyl production, proteolytic and antimicrobial activity, providing safety and sensorial characteristics for the cheese [43].

Manteiga (butter) cheese, also known as *Sertão* cheese, is a very popular cheese consumed in Northeastern Brazil. Its processing includes the addition of *manteiga de garrafa* (bottled butter) to the curd, before the molding step [54]. LAB comprise the predominant microbiota in *manteiga* cheese, mainly *Leuconostoc* sp., *Lactobacillus* sp., *Streptococcus* sp. and *Lactococcus* sp. [55]. *Coalho* (curd) cheese (Fig. 2F) is one of the most consumed and traded cheeses in Brazil. Like *manteiga* cheese, it also plays important role in the socioeconomic development of Northeastern Brazil. Its production involves a curd cooking step and a ripening process during 10 days, resulting in a cheese with slightly salty and acidic flavor, rubber texture, moist appearance and heat resistance [106], [14]. *Levilactobacillus brevis*, *Lactiplantibacillus plantarum*, *L. rhamnosus, Enterococcus* sp., *Lactobacillus* sp., *L. mesenteroides, Streptococcus* sp. and *Weissella* sp. have already been isolated from this cheese type [18, 64], as well as *Candida* sp., *Pichia* sp. and *Kluyveromyces* sp. [52]. LAB isolated from *coalho* cheeses showed diacetyl production and acidification capacity, improving its safety and sensorial characteristics [36]. In addition, Silva et al. [104] demonstrated the presence of peptides with high antioxidant, zinc-binding and antimicrobial activities in *coalho* cheese, suggesting that it could be considered as a functional food.

Caipira cheese is produced in Mato Grosso do Sul State, by following historical and cultural traditions. Raw milk, salt, rennet and an endogenous fermentum are the main ingredients. Its production includes steps as curd cutting, syneresis, molding, manual pressing, dry salting and maturation for 22 days [61]. *Caipira* cheese presents typical flavor, firm texture with or without mechanical eyes. Neither dyes nor preservatives are used during its manufacturing process [57]. *Lactococcus* sp., *L. plantarum*, *L. paracasei* and *L. casei* are the LAB most often found in this cheese [55]. This group presents an antagonistic activity against foodborne pathogens, moderate proteolytic and lipolytic activity and grows in different concentrations of NaCl, pH and bile salts, which emphasizes its biotechnological properties [58].

Finally, *Serrano* (Fig. 2G) is a cheese produced in small farms in the South of Brazil. This cheese is made from raw milk and ripened for at least 22 days. It is a semi-fat and moist cheese, with compact and soft texture (with or without eyes), elastic consistency and yellowish or straw-yellow crust [86]. *Lactobacillus* sp., *Lactococcus* sp. and *Enterococcus* sp. have been found in this product [55]; [89], *Aspergillus*, *Byssochlamys*, *Cladosporium*, *Fusarium*, *Geotrichum, Mucor, Penicillium, Candida, Kluyveromyces, Torulaspora* and *Trichosporon* are the fungi genera already detected in *serrano* cheese [73].

Fermented meat

Socol *Socol* (Fig. 3A–B) is a meat product exclusively produced in Venda Nova do Imigrante City, Espírito Santo State. It originally comes from Italy and was introduced in the region by immigrants in the late nineteenth century. The name *socol* derives from the Italian word "ossocolo," which means "neck." Meat from pig's neck and shoulder region was originally used to make *socol*; however, since it is very rich in fat, *socol* recipe was changed and nowadays it comprises pork loin as the main meat ingredient. In order to manufacture *socol*, pork meat is added with salt (minimum 2.5% w/w), black pepper and garlic, and left to rest for approximately 3 days. Thus, the meat is wrapped in peritoneum or artificial collagen-based wraps; then, it is compressed with the aid of a string net to give structure and shape to the pieces. During the maturation, these pieces are kept in rooms without control of temperature and relative humidity for at least 45 days; by law, the use of heat, drying ovens or any other method that accelerates the maturation processes is not allowed [39, 47, 97]. During this period, LAB such as *Latilactobacillus sakei*, *Latilactobacillus curvatus*, *Levilactobacillus brevis* and *Pediococcus* sp. contribute to the acidification process [30]. After maturation, a coating of filamentous fungi can

Fig. 3 Brazilian fermented meat: **A** *socol* (pork meat) during the ripening process; **B** ripened *socol* covered with filamentous fungi; **C** packed *charqui*

be observed on the surface of the pieces; it plays important roles for the *socol* quality due to the mycobiota with proteolytic and lipolytic activities, contributing to sensorial characteristics [12]. The main fungi genera detected in *socol* are *Penicillium* sp., *Cladosporium* sp. and *Aspergillus* sp. [30]. Excessive fungal covering is often removed by scraping and washing the *socol* pieces with water before packing them for sale, increasing their acceptance by consumers [47].

Charqui *Charqui* (Fig. 3C) is a typically Brazilian meat product. It was used as basis in the diet of poor populations and slaves living in the Brazilian Southeastern, Northern and Northeastern regions throughout the nineteenth century; thus, Southern region took the lead in *charqui* production from investors' perspective at the time, due to successive droughts that affected the Northeastern region and resulted in severe economic difficulties [115]. Jerked beef is a product very similar to *charqui*; however, it is added with sodium nitrite [72]. Both can be used as ingredient in the most classic Brazilian culinary preparation, i.e., *feijoada*, which is cooked with black beans added with different cuts of beef and pork.

Charqui derives from beef subjected to the salting and sun-drying process [79]. Information about the role played by microorganisms in its quality changed the perception that the product was just dehydrated, a fact that brought up, at that time, an important discussion about its classification as fermented meat product with quality similar to that of European meat products [100]. During *charqui* production, the raw material is fermented by autochthonous microorganisms, mainly by *Lactobacillus* sp., *Lactococcus* sp. and *Streptococcus* sp., which contribute to its sensorial characteristics. The production of lactic acid and bacteriocins, in addition to salting and dehydration processes, provide microbiological stability to the product [11, 48], which does not require refrigeration for conservation purposes [51]. In general terms, boneless meat is kept in concentrated brine for hours, later, the pieces are stacked and intercalated with coarse salt overnight. Successive restacking steps are carried out over a few days. After removing the excess of salt, the pieces are suspended in typical metallic structures and dried under the sun. *Charqui* presents maximum water activity of 0.8, maximum humidity of 50%, maximum fixed mineral residue of 23% and minimum sodium chloride of 12% [16].

The use of sodium chloride in meat products, in addition to its sensory and preservative effect, provides stability, reduces undesirable microorganisms and prevents chemical degradation reactions, extending the shelf-life. Furthermore, the inhibition of other microbial groups also contributes to *charqui* quality; halotolerant bacteria, such as *Halobacterium cutirubrum*, can develop in the product due to high salt concentrations [11]. This species produces a red pigment, resulting in red spots on the surface, as well as unpleasant odor and slime [96].

Fermented foods of vegetable origin

Non-alcoholic or low-alcohol beverages

Aluá *Aluá* (Fig. 4A) is a fermented fruit beverage associated with the country's culture. Its origin is controversial, but it is likely an adapted version of the African beverage known as *kissanga*, which was introduced in Brazil by enslaved Africans and adapted to local ingredients and conditions. It results from the natural fermentation of corn, cassava or fruits, such as pineapple, or even stale bread. This beverage can be added with spices, mainly with cloves and ginger, which provide it with special flavor and aroma; it also comprises brown sugar or *rapadura* (a solid molasses type) as sweetening agent [76]. *Aluá* is featured by its slight effervescence and freshness; it is prepared based on a mix of water and basic ingredients, kept at room temperature in order to ferment (at rest) in container covered with cotton cloth for a few days (fermentation time depends on its formulation) [60]. In the case of *aluá* produced from pineapple peel (similar to Mexican *tepache*), 24 h are sufficient for the fermentation process to take place. In the following day, the mix is strained into fabric to remove the peels, and then, spices are added to it. The mix is left to ferment for additional 24 h, strained again, bottled and kept at room temperature for approximately 3 days, for carbonation purposes [103].

Few scientific studies have focused on investigating its microbial composition. *L. paracasei* and two different *L. plantarum* strains (U205 and ABX3) were isolated from this beverage [113]. Silva and Paulo [103] observed pH values of approximately 3.4 after 48-h fermentation, as well as the prevalence of mesophilic aerobic bacteria (1.79×10^8 CFU/mL) and fungi (2.6×10^8 CFU/ml) in *aluá.* Probably, yeasts are responsible by the production of carbon dioxide, which provides its sparkling property, besides aroma and flavor compounds, similarly to the observed for other types of fermented beverages based on fruits [60].

Calugi *Calugi* is a beverage prepared by the indigenous people belonging to Javaé tribe, Tocantins State, Brazil. Corn, cassava and sweet potato are the substrates most often used as raw material, although there are also reports of rice used as fermentative substrate [66, 81]. Overall, cassava is peeled, washed in water and grated in order to get a moist mass, which is then manually squeezed. After the corn is immersed in water for 30 min, it is macerated with the aid of rudimentary wooden devices similar to a mortar and pestle in order to obtain a flour. This flour is mixed to water and strained to form a kind of paste. Next, the cassava and corn pastes are mixed, added with

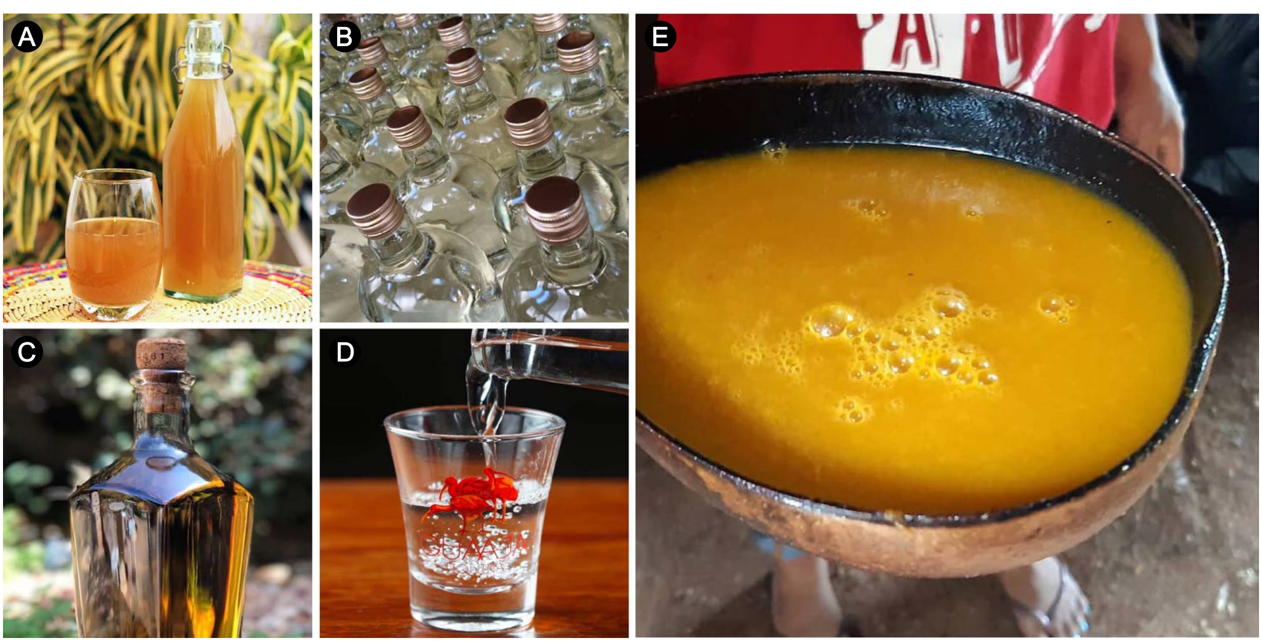

Fig. 4 Brazilian beverages: **A** *aluá*, non-alcoholic fruit-based beverage; **B** bottled *cachaça* (white version); **C** *cachaça* aged in oak barrels; **D** *tiquira*, alcoholic beverage made of fermented cassava; **E** *caxiri*, as known as "Amazon beer," an indigenous alcoholic beverage

water and cooked for approximately 2 h under constant agitation. After cooling, this porridge is inoculated with a portion of sweet potato previously chewed by women in the tribe [67]. The use of saliva as inoculum is frequently mentioned in studies about the production of indigenous fermented beverages [4, 38], and *Lactobacillus* sp. has been identified as a promising starter for this purpose [90, 117]. The porridge aforementioned stimulates the fermentation, as well as provides sweetness to the beverage. The homogenized mix is fermented in open containers at room temperature for 24–48 h. Then, the beverage, which presents creamy consistency and low alcohol content, is ready to be consumed by both adults and children, mainly during meals [67].

Calugi microbiota includes LAB, acetic and mesophilic aerobic bacteria, enterobacteria and yeasts, with predominance of *Bacillus* sp. During the fermentation, organic acids such as lactic, acetic, fumaric, citric, succinic, malic, tartaric, propionic and oxalic acids, besides ethanol and carbon dioxide, are produced; these compounds are responsible for the pH reduction (around 4.0) and the flavor. Other compounds identified in *calugi* include diacetyl, butyric acid and terpene, related to its sensorial properties [63, 66, 67].

Tarubá *Tarubá* is a milky beverage made from cassava, which is prepared by the indigenous people belonging to Sateré-Mawé tribe on the border of Amazonas and Pará states. *Tarubá* production consists in washing, peeling and grating cassava, which is then transferred to a traditional indigenous instrument known as *tipiti* in order to remove its liquid fraction, which is known as *manipueira*. The wet flour obtained is sieved and baked for approximately 30 min, resulting in a kind of biscuit known as *beiju*. It is placed on wooden trays (*gareiras*), covered with *candiúba* (*Trema micrantha*) and/or banana (*Musa* spp.) leaves, moistened with water and left to ferment for approximately 12 days. Unlike other fermented beverages, *tarubá* fermentation takes place in solid substrate. The pulp obtained from the fermentation is diluted in water and subsequently filtered. Often times, this beverage is consumed as tonic on a daily basis [63, 82]. Depending on the fermentation period, low concentrations of ethanol can be found in the beverage (around 0.25 g/kg after 8 days of fermentation) [82]. Regarding to *tarubá* microbiota, LAB are predominant; yeasts play an important role in starch degradation, ethanol production and flavor compounds [110]. *L. plantarum, L. brevis, L. mesenteroides*, as well as *Torulaspora*, *Pichia exigua* and *Candida tropicalis* have already been identified in this beverage [1, 82]. Organic acids detected in *tarubá* include citric, lactic, propionic, succinic and acetic acids [63].

Yakupa *Yakupa* is a spontaneously fermented cassava-based beverage exclusively prepared by women belonging to the Juruna/Yudjá tribe in Mato Grosso State. This refreshing beverage is consumed by both children and adults on a daily basis. Its preparation process consists in soaking cassava roots in water for 2 to 3 days in order to obtain the *puba*. Afterward, it is placed in a structure popularly known as *jirau* and left to dry under the sun for 2 to 5 days. The dehydrated *puba* is kneaded, diluted in water and filtered in order to separate the fibers. The resulting liquid, which is white in color and opaque in appearance, is cooked for 40 min until forming a porridge. Once the porridge is cooled, grated sweet potatoes are added to it; the mix is sieved again and the final product, which is yellowish in color and has slightly sour taste, is obtained. *Yakupa* can be consumed right after its preparation or after re-fermentation for 24–48 h [45, 46, 63].

Its final pH can range from 4 to 5; lactic acid stands out as the main organic acid, followed by acetic, malic and succinic acids; its ethanol concentration is approximately 6.4 g/L. Many volatile compounds, such as acetaldehyde, 1,3-butanediol, butyrate and ethyl lactate, play an important role in the flavor. *L. plantarum* has been identified as the most abundant species in the beverage, whereas *S. cerevisiae* is the main yeast; *L. fermentum*, *Candida krusei* and *Weisella* sp. have also been identified in *yakupa* [45, 46, 63].

Alcoholic beverages

Cachaça The genuinely Brazilian beverage known as *cachaça* (Fig. 4B) is the most consumed distillate in the country, as well as one of the most consumed beverages worldwide [99]. It is the main ingredient of the Brazilian drink known as "caipirinha," which also comprises lemon, sugar and ice. *Cachaça* derives from the process comprising sugarcane juice fermentation and subsequent distillation; it must present alcoholic degree ranging from 38 to 48% per volume with peculiar sensory characteristics [15].

The complex microbial fermentation process of *cachaça* mainly comprises yeast activity, with emphasis on *S. cerevisiae*, although other non-*Saccharomyces* yeasts, such as *Candida*, *Debaryomyces*, *Hanseniaspora*, *Kloeckera*, *Pichia* and *Zygosaccharomyces* can also be involved in the process [101], [78]. The compounds produced by fermenting microbiota include carboxylic acids, higher alcohols, esters, aldehydes and organic acids, which plays an important role in flavor and aroma [6].

Artisanal *cachaça* preparation process comprises a series of steps that start with sugarcane harvesting and grinding. The resulting broth (called *garapa*) is sieved, decanted, diluted at 15° Brix and fermented at 18 °C, for at least 24 h. Depending on the production type, fermentation can take place spontaneously, due to the addition of starter cultures or mixed systems to the broth. An initial yeast population, with features capable of ensuring fermentation yield during the alcoholic production, is added to the vats, before fermentation. This mass of cells used to start the fermentation process is popularly known as *pé-de-cuba*. Many producers add cornmeal or rice bran to it in order to provide extra nutrients for the fermentation process [109].

After the fermentation process is over, the beverage is distilled in stills (*alambique,* in Portuguese), and its undesirable fractions are eliminated. The first, known as *cabeça* (head), can hold significant methanol and ethyl acetate amounts, which must be discarded. The second, known as *coração* (heart), is the noblest part of the beverage; it accounts around 80% of the total distillate. It is a fraction rich in flavor and absent in microorganisms, whose alcohol and esters' contents provide the main features to the beverage. Finally, the last fraction, known as *cauda* (tail), must also be removed due to the presence of unwanted compounds [109]. After collection, *cachaça* can be bottled and sold, or kept in wooden barrels in order to age before it is sold (Fig. 4C).

Tiquira *Tiquira* (Fig. 4D) is a distilled spirit native to Maranhão State [87]. This cassava-based beverage had its origins in Amazonian tribes [65] and is obtained from the simple alcoholic distillate of cassava or fermented juice, the alcohol content must range from 36 to 54% [15]. Its name derives from the indigenous word *ti-kyra*, which means "dripping liquid," since the beverage drips at the end of the distiller [87]. Its preparation process comprises cassava washing, peeling, grating and immediate pressing to avoid its browning. The pressed mass is crumbled on a hot plate, where it forms the *beijus*, which are roasted until they turn slightly golden and decrease their moisture level by approximately 35%. *Beijus* are then covered with banana leaves and kept in warm and humid place, in the dark, for approximately 12 days; it is done to favor the growth of autochthonous fungi on its surface, mainly of *Aspergillus* sp. and *Monilia sitophila*. These microorganisms play an essential role in the production of this beverage, due to amylolytic enzymes production. They account for saccharifying starch and for transforming it into fermentable sugars. After this period is over, *beijus* are crumbled, immersed in water and fermented for 4 days. Then, the must is filtered and the product is distilled in still in order to obtain a spirit with high alcohol content [9, 63]. This beverage is naturally colorless, but tangerine leaves can be added to it to provide it with the traditional bluish color that differentiates it from *cachaça* [94].

The microbiota involved in *tiquira* fermentation include *M. sitophila* and *S. cerevisiae* [95]. Ribeiro et al. [85] have evaluated the microbiota of saccharified *beijus* samples collected in stills in Maranhão State and highlighted the presence of *Aspergillus niger, Aspergillus flavus* and *Rhizopus oryzae. S. cerevisiae* accounted for almost all the identified yeast species (99%) followed by *Candida krusei, Geotrichum capitatum* and *Prototheca zopfii.* The starch saccharification process by the microbiota results in a beverage with a high content of alcohol and metabolites such as ketones, carboxylic acids, phenolic compounds, aldehydes, esters, nitrogen, sulfur compounds and terpenes [31].

Caiçuma *Caiçuma* is a beverage produced by Kanamari indigenous peoples in Amazonas State; it is often consumed on commemorative occasions. It results from the natural fermentation of peach palm fruits (*Bactris gasipaes*), which is a tree native to the Amazon region; the beverage is cloudy and dense, orange (in color) and presents residual pulp [7]. In Mato Grosso State, the *caiçuma* is produced from cassava by the indigenous people from Arara ethnic group [50]. The starchy nature of peach palm fruits or cassava favors the production of alcoholic beverages. For *caiçuma* production, fruits are cooked for approximately two hours; starch gelatinization triggers its partial hydrolysis, which rules out the need of adding amylolytic enzymes to the beverage. In order to reduce the amount of lipids in it, indigenous people often cut the top and base of the fruit to favor the release of part of its lipid content during the cooking process; the released lipid is discarded along with the water. Cooked fruits are pulped and ground, and sugar is added in concentrations ranging from 37 to 50% in order to obtain a viscous mass. The sweetened mass is kept in cloth-covered container to ferment at room temperature for approximately 1 week. Afterward, the fermented mass is diluted in water and left to rest for solid fraction sedimentation purposes. Approximately 2 h later, the beverage is filtered and it can be stored to be consumed later [108]. *Caiçuma* fermentation is carried out by autochthonous microorganisms in a process completely artisanal, but information about its microbiota is scarce. Lacerda [50] isolated LAB from *caiçuma,* highlighting the presence of *L. plantarum* and *Leuconostoc lactis*, besides *Candida tropicalis.*

Cauim *Cauim* is produced by Tapirapés indigenous people in Mato Grosso State; it is served in indigenous rituals and is preferably consumed warm. There are non-alcoholic versions of this beverage, which are consumed by both adults and children. Alcoholic *cauim* is consumed during "Cauinagem," a ritual performed to celebrate the arrival of the harvesting season due to rainfall and the consequent increase in agricultural yield. The aforementioned indigenous people use different substrates, such as rice, corn, peanuts and mainly cassava to produce this beverage [80]. Cassava is kept submerged in water for 4 days to make the peel softer and to degrade toxic cyanogenic compounds. Afterward, *puba* is peeled and dried under the sun. The dry pieces are grated until they form a flour, which is then cooked in water until a kind of gruel is formed. The gruel is left to cool and, then, it is inoculated with sweet potatoes previously chewed by indigenous women in order to trigger the fermentation process. The mix is fermented in open containers, at room temperature, for approximately 48 h [4, 63, 80].

Caium microbiota can vary depending on the substrate used for its production. Bacteria and fungi isolated from the beverage produced from peanuts and rice have been isolated, with emphasis on *Lactobacillus* sp. (which accounted for approximately 40% of the isolated bacteria) [80]. In addition to LAB, *Corynebacterium* sp. (25.2%), *Bacillus* sp. (9.6%) and Enterobacteriaceae (25.8%) were also identified. *Candida* sp., *Kluyveromyces* sp., *Pichia* sp., *Rhodotorula* sp. and *Saccharomyces* sp. stood out among the yeast species found in the beverage. On the other hand, Almeida [5] evaluated *cauim* produced from cassava, highlighting the presence of *Bacillus* sp., *Candida* sp., *Corynebacterium* sp., *Cryptococcus* sp., *Debaryomyces* sp., *Lipomyces* sp., *Enterobacter* sp., *Lactobacillus* sp., *Paenibacillus* sp., *Pichia* sp., *Serratia* sp. and *Trichosporon* sp. Organic acids, mainly lactic and acetic acid, ethanol and other antimicrobial components provide the final microbiological stability and safety of the product [69], [4].

Caxiri *Caxiri* (Fig. 4E) is exclusively produced by indigenous women belonging to the Yudjá/Juruna tribe in Amazon region; this beverage, popularly known as "Amazon beer," is obtained from cassava, corn and sweet potatoes. Its consumption is associated with religious rituals and practices, as well as with collective community work, such as planting and felling trees. The production process includes a *pubagem* step during 2 days; *puba* is peeled, grated and then pressed in *tipiti* to remove the liquid portion from it. The resulting mass is roasted (a process that helps detoxifying bitter roots) in order to produce a flour. This flour is then mixed to water and sieved; the removed liquid is added with grated sweet potato and placed in barrels to ferment at room temperature for 24 or 48 h. *Caxiri* is often consumed within 120 h after its preparation; this time can affect the alcohol content in the beverage, which is often close to 10% (v/v) [93].

The final pH of *caxiri* is close to 3.0; maltose is the main fermentable carbohydrate in it (0.33 g/L after 120-h fermentation). Lactic acid is the main organic acid resulting from the fermentation process; compounds such as glycerol, esters and alcohols account for the aroma. *Bacillus* spp., *L. fermentum*, *Lactobacillus helveticus*, *Sphingomonas* sp., *Pediococcus acidilactici*, in addition to *Rhodotorula mucilaginosa, Pichia* sp., *Cryptococcus* sp. and *S. cerevisiae* have been identified in the beverage [68], [92].

Fermented foods based on cassava

Cassava (*Manihot esculenta*) is a tuberous root grown in different Brazilian regions. The economic importance of cassava crops comes from the interest in its roots, which are rich in starch, used as human and animal food, as well as in the manufacture of food and industrial products. Different Brazilian fermented foods types can be prepared based on cassava roots, mainly those of indigenous origin (Fig. 5).

Puba or Carimã *Puba* or *carimã* (from the Tupi indigenous language = cassava sour mass) (Fig. 5D) is a product obtained through the spontaneous fermentation of cassava roots submerged in water [10]. Roots are traditionally peeled and immersed in some stagnant water or kept inside a bag submerged in running water, where they are left to ferment for up to seven days. The activity of indigenous cassava microorganisms leads to root softening and to the degradation of toxic compounds often found in wild cassava. After the fermentation process is over, roots are pressed to remove the fibers. The resulting mass is washed, pressed with a cloth to remove the liquid fraction from it and, finally, it is left to dry under the sun in order to obtain the so-called *puba seca* (dried *puba*), which presents 13% of humidity [33]. *Puba* is appreciated and consumed in different ways; it is widely used to prepare savory dishes, cakes, cookies, sweets, porridges and mush, among others.

Scientific studies conducted with *puba* are relatively scarce. Almeida [3] reported the prevalence of *Corynebacterium* sp., *Erwinia* sp., *Klebsiella* sp. and *Streptococcus* sp. in the first 24-h fermentation; their populations were gradually outnumbered and replaced by LAB after 48-h fermentation. Crispim et al. [33] demonstrated the prevalence of LAB it the product, mainly *L. fermentum* followed by *L. delbrueckii* and *L. plantarum*. In addition, the aforementioned authors observed the significant antagonistic activity of *L. plantarum* and *L. fermentum* strains isolated from the *puba*, which may provide important protective effect against food pathogens, mainly on products prepared based on poor hygiene and sanitation practices. *Bacillus* sp. have also been recovered from *puba*. The fermenting microbiota produces several organic acids, such as lactic, butyric and acetic acids, which extend the shelf life of *puba* [40].

Farinha d'água *Farinha d'água* (Fig. 5B) is a fermented cassava flour deriving from the Amazonian region; it is

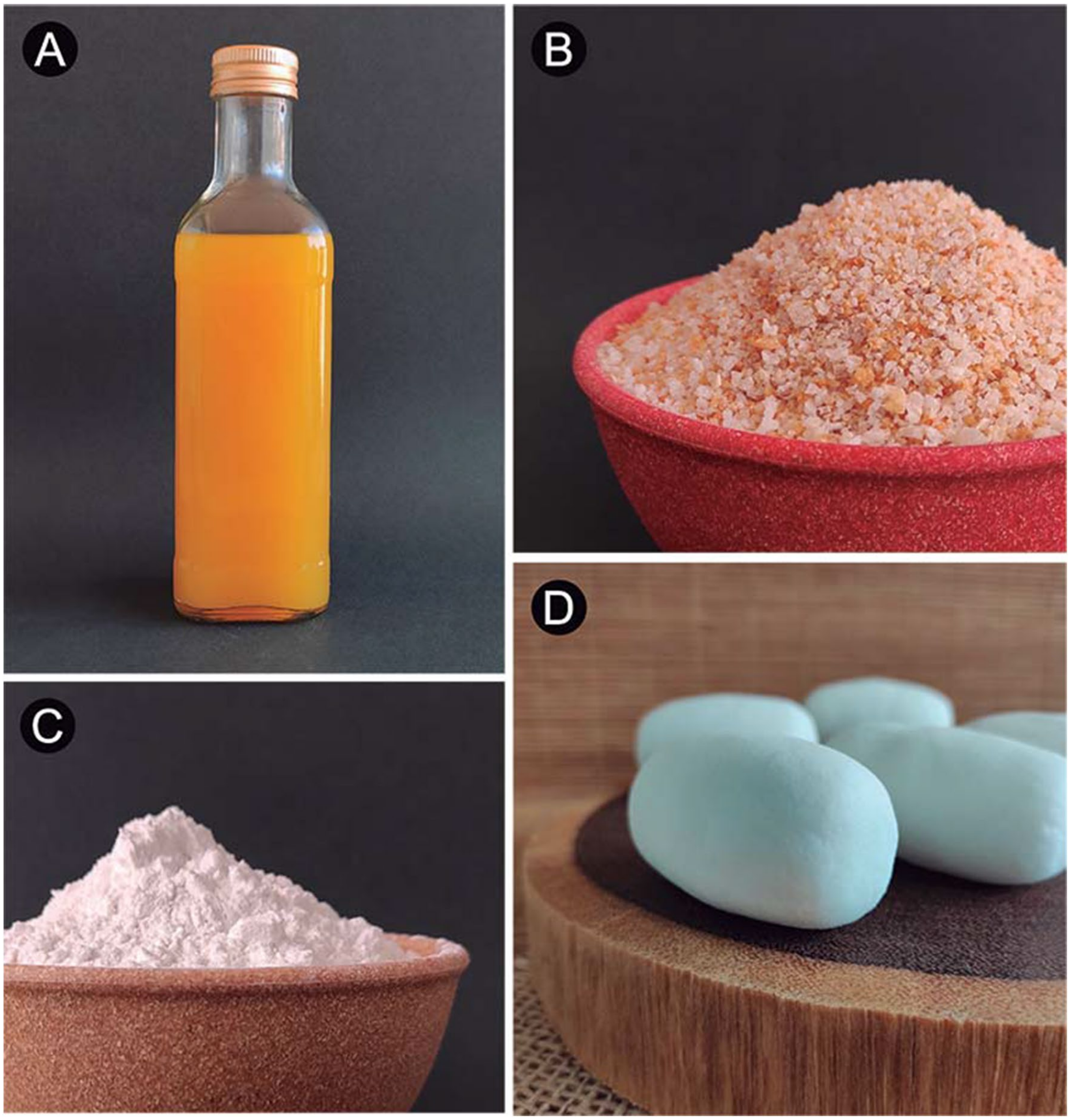

Fig. 5 Brazilian fermented food based on cassava: **A** *tucupi* (fermented cassava juice); **B** *farinha d'água* (dried and fermented cassava flour); **C** *polvilho azedo* (fermented cassava starch); and **D** manually shaped *carimã/puba* (fermented and drained cassava pulp)

widely consumed in different states in Northern Brazil, mainly in Pará State [28]. It is virtually a mandatory side dish at meals in the local population, as well as used in different preparations, such as *farofa* (crumble), *pirão* (a kind of fish porridge), and classic cakes typical of the Brazilian Northeastern cuisine [10]. It is legally defined as a product deriving from cassava roots, which is properly cleaned, macerated, peeled, crushed, ground, pressed, dismembered, sieved, dried at moderate temperature – it can be sieved again. It has larger granules than those of other flours, it can be classified as "fine" (when up to 30% of the flour is retained in 10-mesh sieve) and as "course" (when its retention degree exceeds 30%) [13].

In general terms, *farinha d'água* is obtained through the fermentation of cassava submerged in water for approximately 5 days. After, roots are peeled, crushed, pressed, sieved and dried in order to produce *farinha d'água* [26]. Coelho et al. [32] identified different species of mesophilic heterotrophic bacteria, such as *Lactobacillus* spp. and *Streptococcus* spp., in addition to *Candida castellii, C. ethanolica, C. krusei, Pichia membranifaciens* and *Trichosporon asahii.* According to the authors, some yeasts presented amylolytic activity, contributing to the releasing of fermentable sugars and, consequently, to the fermentation process.

Polvilho azedo *Polvilho azedo* (sour cassava starch) (Fig. 5C) can be defined as starchy product extracted from cassava subjected to fermentation and sun-drying process. Fermentation provides this product with a high expansion capacity. *Polvilho azedo* is widely used to manufacture bakery products, mainly *pão de queijo* (cheese bread), which is a classic Brazilian cuisine product. Washing and peeling are the first cassava processing steps. Then, roots are grated, and this process results in plant cells' disruption and in the consequent release of starch granules. The resulting mass is repeatedly washed until total starch removal. This operation is carried out by adding water to the mass, which is strained with the aid of fine overlapped cloths until the washing water looks virtually clear. The milky liquid containing starch is distributed to settling tanks [10]. After, the starch decanted, it is kept in covered tanks in order to ferment at room temperature for 15 to 40 days until the product reaches acidity level around 5% and pH close to 4.5 [37].

Subsequently, the fermented starch is removed from the tanks and transferred to *jiraus* in order to dry under the sun (until their humidity level becomes lower than 14%). The fermentation conditions of *polvilho azedo* comprise substrate exclusively formed by granular starch, which is used as carbon source for microorganisms; almost-solid medium formed by starch decantation in the tank; as well as anaerobic conditions, which are established in the first five fermentation days [71]. There is intense bubble formation during the first fermentation stages, although they decrease as the process evolves until all bubbles disappear, which means the end of the process [77]. Despite the development of new drying technologies, such as industrial dryers, the exposure to the sun results in higher-quality *polvilho azedo*, since ultraviolet radiation leads to compound oxidation, as well as changes dextrins' features [10]. Besides that, amylolytic enzymes significantly change the structure of starch granules during the fermentation process, as well as provides unique technological properties [8]. *Lactobacillus* sp.is the prevalent genus in the herein described fermentation process; it is followed by *Streptococcus* sp., *Enterococcus* sp., *Leuconostoc* sp., *Pediococcus* sp. and *Lactococcus* sp. [71]. In addition to LAB, *Propionibacterium* sp. and *Clostridium* sp. are also involved in this process [10].

Tucupi *Tucupi* (fermented cassava sauce) (Fig. 5A) is a yellowish liquid deriving from the fermentation of wild cassava juice which is produced by indigenous peoples and communities living in Northern Brazil. Cassava is traditionally squeezed in *tipiti* in order to separate the solid from the liquid fraction. The liquid fraction (*manipueira*) is left to rest at room temperature in order to ferment for 3 days. During this period, residual starch settles to the bottom of the container; then, it is removed and used to produce other type of foods, such as *polvilho*. The fermented juice is boiled with different spices to provide *tucupi* with characteristic flavor, which is significantly appreciated in the Amazon region and has recently enabled *tucupi* to gain increasing prominence in the Brazilian gastronomic scenario [17, 27]. *Tucupi* is the main ingredient of *tacacá*, which is a typical dish of Northern Brazil, and also includes dried shrimp, tapioca gum and *maniçoba* (previously cooked cassava leaves); in addition, it can be used to prepare a sauce served with roasted duck (*pato com tucupi*), which is one of the main dishes served in the religious festivities [22, 62].

Caetano [19] evaluated *tucupi* samples purchased at different supermarkets in Belém City, State of Pará, and the results emphasized the role played by LAB in the fermentation process. *L. fermentum* (50%), *L. plantarum* (39.3%), *L. acidophilus* (7.1%) and *L. parabuchneri* (3.6%) were the prevalent species observed. On the other hand, *Candida ethanolica, Candida humilis, Candida anomalus, Pichia exigua, Pichia scutulata, Wickerhamomyces anomalus* and *Y. lipolytica* were the main yeasts identified. Products deriving from wild cassava must be prepared with caution, since it has cyanogenic glycosides that are potentially harmful to human health. Although *manipueira* is boiled in order to eliminate hydrocyanic acid (HCN), high HCN concentrations have been reported in this product [27]. Thus, this fermentation process can play an important role in reducing cyanogenic compounds in the raw material, since the longer its duration, the lower the HCN content in the final product [29]. Acidification and consequent pH reduction during fermentation inhibit the linamarase enzyme activity, and it significantly reduces cyanide release. The same effect is obtained through boiling process, due to toxic compound volatilization at high temperatures [10]. Thus, studies have recommended fermenting *manipueira* for at least 24 h, as well as cooking it for at least 10 min after the fermentation, to obtain a final product with pH close to 4.0 and cyanide content lower than 10 mg/L, in order to guarantee its security [17, 21].

Final remarks

The current review has presented some typically Brazilian fermented foods types that either derive from native traditions or were incorporated from other cultures and adapted to Brazil. It has emphasized that many food types, mainly the indigenous ones, are exclusively produced and consumed by these populations, and remain unknown to other Brazilians. It is essential conducting further studies focused on investigating fermented foods, whether at the fermentation microbiology or sociocultural nature scope, to help improving the knowledge about this emblematic food group. The information presented in this review can encourage other researchers in this field to contribute to the knowledge about Brazilian fermented foods types.

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