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Food fermentation: an overview of current fermenting processes in traditionally fermented and consumed foods

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Abstract

Fermented foods and beverages play a significant role in most societies and have a major role in population protein requirements. Food fermentation is one of the oldest biotechnology processes which play an important role in enrichment and improvement of food through enhancement of flavour, aroma, protein, essential amino acid and vitamins. Moreover, this technology can also be used to change food texture, preserve food through acetic acid, lactic acid, alcoholic and alkaline fermentation, detoxify foods and reduce the cooking time. Different foods can be produced by fermenting cereals, tubers, fruits, and fish. The fermentative process of food worldwide is generally spontaneous and leads to a highly fluctuating product quality. The use of starters could be an alternative to ensure the safety and quality of fermented products in Africa. The objective of this review is to point out the fermentation approaches and initiatives used to improve various traditionally fermented food worldwide.

Keywords: Traditional Fermentation, food, microorganisms, starters

Résumé

La fermentation est l'un des processus biotechnologiques les plus anciens. En effet, elle joue un rôle important car elle permet d'apporter une valeur ajoutée au produit final par l'amélioration de la saveur et de l'arôme grâce à la production des protéines, des acides aminés essentiels et des vitamines. De plus, cette technologie peut également être utilisée pour modifier la texture des aliments et les conserver grâce à l'acide acétique, l'acide lactique produit par les microorganismes. Différents aliments peuvent être produits par fermentation des céréales, des tubercules, des fruits de la viande et du poisson. Cependant, le processus de fermentation des aliments dans le monde entier est généralement spontané, conduisant ainsi à des produits de qualité variable. L'utilisation de starters pourrait alors être une alternative pour garantir la sécurité et la qualité des produits fermentés en Afrique. L'objectif de cette revue est de mettre en évidence les approches des fermentations utilisées pour améliorer la qualité de divers aliments traditionnellement fermentés dans le monde.

Mots-clés: Fermentation spontanée, aliments, microorganismes, starters

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Introduction

Fermentation is one of the oldest and most important food processing techniques (Blandino et al., 2003) for conservation and recovery of food byproducts. Fermented foods make a major contribution to human nutrition worldwide. Indeed, many fermented foods have health benefits and some have curative properties against many diseases and disorders. Thus, fermented foods are more attractive and nutritious than non-fermented food substrates. The microorganisms involved in fermentation processes include bacteria, molds and yeasts (Camus, 2011, Tamang and Fleet 2009). These microrganisms are used in many ways to produce various traditional food of different quality, strongly depending on the processing technique. In general these techniques need to be improved in order to obtain better quality products. Bacteria are the most dominant microorganisms in both naturally fermented foods and foods fermented using starter cultures. Among these bacteria, lactic acid bacteria (LAB) are commonly associated with acidic fermented foods, while non-LAB bacteria such as Bacillus, Micrococcaceae, Bifidobacterium, Brachybacterium, Brevibacterium, and Propionibacterium etc., are also involved in food fermentation, frequently as minor or secondary groups. Lactic acid bacteria are Gram-positive, catalase-negative bacteria that produce large amounts of lactic acid. The bacterial groups that make up the LAB are among the most familiar to humans, because of their association with the human environment, and with a wide range of naturally fermented dairy products, grain crops, vegetables...etc. The LAB comprise a large bacterial group consisting of about 380 species in 40 genera of 6 families, belonging phylogenetically to the order Lactobacillales within the phylum Firmicutes. Common genera of the LAB isolated from various fermented foods of the world are Alkalibacterium, Carnobacterium, Enterococcus, Lactococcus, Lactobacillus, Leuconostoc, Oenococcus, Pediococcus, Streptococcus, Tetragenococcus, Vagococcus, and Weissella (Carr et al. 2002). Bacillus is reported from the alkaline-fermented foods from Asia and Africa (Parkouda et al., 2009). Species of Bacillus present in fermented foods mostly soybean-based foods are *B. amyloliquefaciens, B. circulans, B. coagulans, B. firmus, B. licheniformis, B. megaterium, B. pumilus, B. subtilis, B. subtilis* and *B. thuringiensis* (Kiers et al., 2000, Kubo et al., 2011), while strains of *B. cereus* have been isolated from the fermentation of *Prosopis africana* seeds for the production of okpehe in Nigeria (Oguntoyinbo et al., 2007). Some strains of *B. subtilis* produce λ-polyglutamic acid (PGA) which is an amino acid polymer commonly present in Asian fermented soybean foods giving the characteristic sticky texture to the product. Species of Bifidobacterium, Brachybacterium, Brevibacterium, and Propionibacterium have been isolated from cheese and other fermented milks (Bourdichon et al., 2012). Several species of Kocuria, Micrococcus, and Staphylococcus have been reported from fermented milk products, fermented sausages and meat and fish products (Wu et al., 2000; Coton et al., 2010). *Enterobacter cloacae, Klebsiella pneumoniae, K. pneumoniae subsp. ozaenae*, Haloanaerobium, Halobacterium, Halococcus, Propionibacterium, Pseudomonas, and so on, are also present in many fermented foods (Tamang 2010b). The role of yeasts in food fermentation is to ferment sugar, produce secondary metabolites, inhibit growth of mycotoxin-producing molds and display several enzymatic activities such as lipolytic, proteolytic, pectinolytic, glycosidasic and urease activities (Aidoo et al., 2006). Genera of yeasts reported from fermented foods, alcoholic beverages and nonfood mixed amylolytic starters are Brettanomyces, Candida, Cryptococcus, Debaryomyces, Dekkera, Galactomyces, Geotrichum, Hansenula, Hanseniaspora, Hyphopichia, Issatchenkia, Kazachstania, Kluyveromyces, Metschnikowia, Pichia, Rhodotorula, Rhodosporidium, Saccharomyces Saccharomycodes, Saccharomycopsis, Schizosaccharomyces, Sporobolomyces, Torulaspora, Torulopsis, Trichosporon, Yarrowia, and Zygosaccharomyces (Watanabe et al., 2008, Tamang and Fleet 2009, Kurtzman et al., 2011). The major roles of fungi, mostly filamentous molds, in fermented foods and alcoholic beverages are the production of intra- and extracellular proteolytic

enzymes that highly influence the flavor and texture of the product, and also the degradation of antinutritive factors by improving minerals bioavailability. Species of Actinomucor, Amylomyces, Aspergillus, Monascus, Mucor, Neurospora, Penicillium, Rhizopus are reported from many fermented foods (Nout and Aidoo 2002).
In developed countries, many fermented foods and beverages are made from selected strains called starters (Tamang, 2007) while in developing countries it is more more about preservation of perishable foodstuffs (Kalui et al., 2010). Moreover the obtained products are not always standardized in developing countries. Different foods can be produced through cereals, tubers, fruits, and fish fermentation. The fermentative process of food is generally spontaneous and leads to a highly fluctuating product quality. Extrinsic and intrinsic factors, such as temperature, humidity, hygiene, appropriate preservation techniques and the nature of the raw materials always determine the quality of the final product. This literature review presents the diversity of fermented foods consumed worlwide, the different fermentation approaches and initiatives to improve the fermentation process.

Fermentation technologies and food diversification

The role of microorganisms in food technology diversification

Different types of bacteria are generally known to be involved in food processing and according to the bacterial type and characteristics, the food fermentation process can either be alkaline, alcoholic acid, dry, wet or even lactic (Table 1). However, the diversification can be more important since new technologies in bacterial identification is providing new insight in bacterial function. Indeed, a recent work on the microbiome of eight african countries comprising dairy, alcoholic, cassava, bean based fermented foods highlighted the presence of numerous bacteria (Diaz et al. 2018). The most abundant bacteria in cereal and dairy fermentations were genera within the order Lactobacillales such as Lactobacillus, Weissella and Streptococcus. Lactobacilli were identified as Lactobacillus fermentum. Acetobacter, were also found at relatively high abundances in some of the dairy and cereal fermented samples. The genus Zymomonas which had not previously been described in fermented dairy or cereal samples was also found. In the sample of fermented cassava that showed a similar diversity to the cereal and dairy samples, Lactobacillus and Weissellawere were the most abundant genera, whereas the other sample showed high levels of bacteria from Lactobacillus, Leuconostoc, Weissella, Bacillus and Enterobacteriaceae. Alcoholic fermented samples contained abundantly Zymomonas, Leuconostoc and Bacillus. Zymomonas, Gemella, Brevibacillus, Jeotgalicoccus, Atopostipes and members of the family Carnobacteriaceae which have never been reported in legume fermented food were also found.

Technologies applied to obtain fermented fruit based foods

Soumbara, a baobab groundnut base food

Soumbara is a product obtained by the alkaline fermentation of protein and oil seeds, particularly those of African or nereal carob (*Parkia biglobosa*), baobab (*Adansonia digitata*), groundnut (*Arachis hypogeae*), Guinea sorrel (*Hibiscus Sabdariffa*) and soybean (*Glycine max*). This condiment consumed in West and Central Africa (Mertz et al., 2001; Yagoub et al., 2004) has several names related to the type of oilseeds processed, the countries of origin and the ethnic groups that produce it (Ibrahim et al., 2011; Agbobatinkpo et al., 2013; Fatoumata et al., 2016). Soumara is used in the preparation of dishes to enhance the taste of sauces accompanying cereal-based dishes such as rice, millet, sorghum, maize etc (Ibrahim et al., 2011; Agbobatinkpo et al., 2013; Fatoumata et

Table 1. Characteristics of few different fermented foods produced around the world.

Raw material	Characteristics of fermentation process	Microorganisms involved	Main end products	Regions of production	References
Oil seeds or beans from nereal carob (Parkia biglobosa), baobab (Adansonia digitata), groundnut (Arachis hypogeae), Guinea sorrel (Hibiscus Sabdariffa) and soybean (Glycine maxima)	Alkaline fermentation	Bacteria of the genus Bacillus, mostly *Bacillus subtilis*	Soumabara, Dawadawa	West and central African countries	Omafuvbe et al., 2004; Ouoba et al., 2004; Amoa-Awua et al., 2006; Azokpota et al., 2007; Meerak et al., 2008, Adjoumani et al., 2019.
Coffee beans	Dry or wet processing/ Alcoholic and acid fermentation	Yeasts, lactic acid bacteria, and bacteria of the genus *Bacilus*	Coffee	Tropical regions of Africa, America and Asia	Vilela et al., 2010; Evangelista et al., 2014; Hamdouche, 2015.
Cocoa beans	Acoholic and acid fermentation	Yeasts, lactic acid bacteria, acetic acid bacteria and bacteria of the genus *Bacillus*	Chocolate	Tropical regions of Africa, America and Asia.	Tompson et al., 2001; Ardhana and Fleet, 2003; Schwan and Wheals, 2004; Ouattara and Niamke, 2021.
Palm sap	Acoholic fermentation	Yesats, lactic acid bacteria, acetic acid bacteria	Palm wine (Beverage)	West and central Africa, Southeastern Asia	Endo et al, 2014; Konaté et al., 2015; Ple'C *et al.,* 2015.
Millet	Lactic fermentation Alcoholic fermentation	Lactic acid bacteria, yeasts	Womi	West Africa	Sahoré *et al.,* 2007.
	Lactic fermentation Alcoholic fermentation	Lactic acid bacteria	Baca	West Africa	Mouroufié et al., 2018; Soro et al., 2013.
Rice	Lactic fermentation Alcoholic fermentation	Lactic acid bacteria, yeasts	Idli	India, Sri Lanka	Sands & Hankin, 1974; Nagaraju & Manohar, 2000.
	Lactic fermentation Alcoholic fermentation	Lactic acid bacteria, yeasts	Dosa	India, Sri Lanka	Sands & Hankin, 1974; Nagaraju & Manohar, 2000; Battacharya & Bhat, 1997.

Table 1: To be continued

Wheat	Acoholic fermentation, Alkaline fermentation, Bacillus Fermentation	Molds, yeasts bacteria of the genus *Bacillus*	Soy sauce	Japan, China and the Far East countries	(Beuchat, 1983; Mensah, 1997).
	Lactic fermentation Alcoholic fermentation	Yeasts, lactic acid bacteria	Tarhana	Turkey	Campbell-Platt, 1994; Economidou & Steinkraus, 1993; Ozdemir et al., 2007.
Corn	Lactic fermentation Alcoholic fermentation	Molds, yeasts, lactic acid bacteria	Kenkey	Ghana	Jespersen et al., 1994. Nout et al., 1995.
	Lactic fermentation Alcoholic fermentation	Yeasts, lactic acid bacteria	Doklu	Cote d'Ivoire	Brou et al., 2008.
	Lactic fermentation Alcoholic fermentation	Molds, yeasts, lactic acid bacteria	Ogi	West Africa	Blandino *et al*., 2003.
	Lactic fermentation	Lactic acid bacteria, yeasts and non lactic acid bacteria	Pozol	South-eastern Mexico	Nuraida et al., 1995; Díaz-Ruiz et al., 2003; Nanson & Field, 1984; Wacher, 1993.
	Alcoholic fermentation, Lactic fermentation.	Yeast, lactic acid bacteria	Chicha (beverage)	South-America	Haard et al., 1999; Vargas-Yana et al., 2020.
Sorghum	Lactic fermentation	Lactic acid bacteria,	Injera	Ethiopia	Neela &Fanta ,2020.
	Lactic fermentation	Lactic acid bacteria,	Kisra	Sudan, Arabian Gulf	Adebo, 2020; Sushma et al., 1995.
Wheat, Corn, Rice	Lactic fermentation.	Lactic acid bacteria	Boza (beverage)	Bulgaria, Albania, Turkey, and Romania	Hancioglu & Karapinar, 1997; Muhammet & Orhan, 2020.
Corn, millet…	Acoholic fermentation	Yeasts, lactic acid bacteria	Tchapalo (beverage)	West Africa	Aka *et al*., 2017; Assohoun *et al*., 2012.
Cassava roots	Lactic fermentation	Yeasts, lactic acid bacteria and bacteria of the genus *Bacillus*	Attiéké,	Côte d'Ivoire	Assanvo *et al*., 2006; Coulin *et al*., 2006.
	Lactic fermentation	Yeasts, lactic acid bacteria and bacteria of the genus *Bacillus*	Gari	Benin, Togo	Moslehi-Jenabian *et al.,* 2010.

According to Campaore et al (2013) and Oguntoyinbo (2007) soumara is also an important source of protein for low-income families. In addition to being a seasoning, soumara has therapeutic virtues. Indeed, this food has the ability to lower blood pressure (Gutierrez et al., 2000; Diawara and Jakobsen, 2004), and is therefore recommended for people with high blood pressure. (Gutierrez et al., 2000).

The preparation of soumbara requires a first step of boiling the grains of néré for 24 to 40 hours. After shelling, a second boiling is carried out for 1 to 2 hours. Then, fermentation takes place for 24 to 72 hours at room temperature and then air drying is carried out. After drying, balls of different sizes are made from the grains. According to Ouoba et al. (2004), the main microorganisms involved in the fermentation of néré are bacteria of the genus Bacillus.

Studies carried out by Adjoumani et al. (2019) on the characterization of soumara microflora in the six major producing regions of Côte d'Ivoire revealed that Ivorian soumara has a high microbial diversity. It is essentially composed of 10 species of Bacillus representing more than 90 % of total microbial isolates, 3 species of lactic acid bacteria (*Streptococcus oralis; Enterococcus feacium; Weissella cibaria*), 2 species of Staphylococcus (1.42%), 8 fungal species (4.61 %) and 1.06 % of other microorganisms. It should be noted that two species including Bacillus subtilis and *Bacillus velezensis* were present in samples from all regions studied. These Bacillus species seem to be the most adapted to soumara since these bacteria have also been found in many other countries in Africa such as Benin, Nigeria, Burkina Faso, Mali, Senegal and Ghana (Omafuvbe et al., 2004; Ouoba et al., 2004; Amoa-Awua et al., 2006; Azokpota et al., 2007; Meerak et al., 2008).

The results of work carried out by Ibrahim et al., (2011), Ibeabuchi et al., (2014) and Fatoumata et al., (2016) on the microbiological characteristics of some fermented foods have highlighted the involvement of lactic acid bacteria, yeasts and moulds in this type of fermentation. Thus, by their lytic activity (proteolysis, amylolysis, lipolysis, etc.) (Enujiugha, 2000 ; Ibeabuchi et al., 2014), they modify the biochemical, nutritional and sensory characteristics of processed seeds (protein and oilseeds) (Koné, 2001). These sensory changes contribute to the typicality of soumara which can sometimes be difficult to consume if one is not used to it.

Food from coffee beans

The coffee (*Coffea canephora*) robusta variety, remains the most widespread variety in Africa and represents about 30 % of world production. After harvesting, the coffee undergoes a series of processing operations before being exported as a "merchant green bean". The initial processing consists of detaching the beans from the cherry husks and removing the husks (exocarp, pulp, parchment and skin). There are two methods of freeing the coffee bean from its surroundings, including dry and wet processing (Schwan and Wheals, 2004). The wet process involves a fermentation step that is a degumming technique. However, this technological operation has an important impact on the quality of the finished product, as it influences its characteristics. For example, coffee processed by this method is generally considered to be of higher quality and is traded at higher prices (Hamdouche, 2015). The organic acids, released during fermentation, lead to a more acidic and appreciated product. Fermentation, which occurs spontaneously, therefore allows the exocarp to be eliminated, under the joint action of enzymes. Two distinct processes develop during fermentation. These are the hydrolysis of the mucilage associated with an acidification of the medium and the diffusion of compounds towards the outside of the bean (sugars and to a lesser extent, chlorogenic acids and caffeine). The fermentation itself consists of depositing the coffee pulped by the action of water in concrete or metal tanks (Barel, 2008). The duration of fermentation varies from 24 to 90 hours depending on the ambient temperature and the degree of maturity of the cherries. Some authors advise to practice this fermenta

tion, which they consider solid because the medium is sufficiently acidified to allow the intrinsic biochemical changes of green coffee to occur under water.
The main bacterial genera isolated from coffee belong to both Gram-negative (Aeromonas, Pseudomonas, Enterobacter and Serratia, Acinetobacter, Klebsiella, Escherichia) and Gram-positive bacteria. (Bacillus, Cellulomonas, Arthrobacter, Microbacterium, Brochothrix, Dermabacter and Lactobacillus). Most isolated yeasts belong to the genera Pichia, Candida, Arxula, Debaryomyces, Saccharomycopsis, Saccharomyces, Torulaspora and Rhodotorula (Vilela et al., 2010; Evangelista et al., 2014). The main genera of moulds found are Cladosporium, Fusarium, Penicillium, Aspergillus. Beauvaria, Monilia, Rhizoctonia and Arthrobotrys (Silva et al., 2000; Vilela et al., 2010). Some species of the genus Aspergillus and Penicillium, isolated from green coffee beans are potentially ochratoxinogenic (Batista et al., 2003).

Food obtained from cocoa beans

Cocoa (*Theobroma cacao* Linné) is grown for its beans, which are not only the raw material for the chocolate industry (Ardhana and Fleet, 2003) but also a vital export product for many countries in America (Central and South), Asia (South and South-East) and especially Côte d'Ivoire. The technological transformation of cocoa into chocolate and cocoa products requires a primary post-harvest handling process involving debarking, fermentation, drying and storage. Fermentation of cocoa is a critical step in obtaining good quality market beans as it contributes to the development of the organoleptic characteristics of chocolate (Afoakwa et al., 2008) and facilitates drying by pulping the beans. There are four fermentation methods (Fowler, 1999), namely heap fermentation on banana leaves, in tubs or crates, fermentation in baskets and fermentation on drying trays. According to the studies carried out by Brou et al. in 2018, banana leaves are the most commonly used fermentation material, with an average frequency of 67.33 % in Côte d'Ivoire. In all localities, producers practice fermentation with heterogeneous durations ranging from 2 to 7 days in Abengourou, 3 to 7 days in Oumé and 3 to 8 days in Soubré. However, operations lasting less than 6 days are more frequent in the Centre-West (72%) and South-West (64%) than in the East (46%). The stirring of the mass of cocoa beans during fermentation is practically non-existent in the different production zones (Brou et al., 2018). It should be noted that poor fermentation leads to poor quality beans for chocolate. Thus an absence of fermentation results in slatey, astringent and flavourless beans. A short fermentation leads to purple, bitter, astringent beans with little aroma. Too long fermentation produces rotten beans (Barel, 1995). The fermentation of cocoa is ensured by a succession of four main germs including yeasts, lactic acid bacteria, acetic acid bacteria and bacteria of the genus Bacillus (Tompson et al., 2001; Ardhana and Fleet., 2003; Schwan and Wheals, 2004; Ouattara & Niamké, 2021). Koffi et al. showed in 2017 that yeasts isolated in six major cocoa-producing regions of Ivory Coast are dominated by the species Pichia kudriavzevii, Saccharomyces cerevisiae and Pichia kluyveri. As for lactic acid bacteria, studies conducted by Adiko et al. (2018) revealed the presence of four genus including Lactobacillus, Leuconostoc, Weissella and Enterococcus.
The fermentation of cocoa facilitates the drying of the beans by removing the pulp, but also and above all by inducing biochemical reactions in the bean leading to the formation of precursors of chocolate flavour (Thompson et al., 2001). This is a crucial stage where several biochemical reactions take place either on the surface or inside the bean. The reactions on the surface on the bean eliminate the external mucilage of the bean by the action of pectinolytic enzymes produced by yeasts and bacteria of the genus Bacillus. During these initial reactions, compounds are produced including

ethanol, acetic and lactic acids, acetoin, mannitol, under the action of yeasts, lactic, acetic and Bacillus bacteria. The oxidation of ethanol to acetic acid is a very exothermic reaction which induces a rise in the temperature of the fermenting cocoa mass. Conditions of high heat favour the diffusion of microbial metabolic products (mainly acetic and lactic acids) inside the beans (Jinap, 1994).
During the reactions inside the bean, the diffusion of organic acids combined with high heat induces the suppression of cotyledon germinative capacity and therefore causes the degradation of storage cells containing lipids and polyphenols (Thompson et al., 2001). The entry of organic acids into the bean causes the pH to drop from (6.3-6.8) to (4-4.5) (Lopez and Dimick; 1995). This promotes the activation of endogenous hydrolytic enzymes, including an aspartic endoprotease and a serine carboxypeptidase. The endoprotease hydrolyses the globular reserve proteins of the bean to yield hydrophobic oligopeptides which are subsequently hydrolysed by the serine carboxypeptidase to hydrophobic free amino acids, identified as specific precursors of cocoa flavour (Serra and Ventura, 1997). In addition, oxidation of polyphenols occurs, resulting in the disappearance of cocoa astringency (Serra and Ventura, 1997). Hydrolysis of anthocyanidins into anthocyanidins and sugars (galactose and arabinose) also occurs, which, through oxidation, take on a brown colour, characteristic of "well-fermented" cocoa. Reductions of 93% in polyphenols after 4 days of fermentation have been reported (Wollgast and Anklam, 2000).

Fermented palm wine

Palm wine is a drink obtained from the fermentation of palm leaves (*Elaeis guineensis*) by indigenous microbes. Palm wine is obtained from the palm tree (*E. guineensis*). It undergoes spontaneous fermentation, which promotes the proliferation of microorganisms because of its nutritional content. The presence of microbial populations in this beverage is of paramount importance to public health given the specific role of organisms (Ple'C et al., 2015). The presence of a large population of lactic acid bacteria could have a beneficial effect on the health of the consumer and thus increase the interest of this drink. The sap of the palm tree is subjected to a spontaneous fermentation that promotes the proliferation of yeast species for the transformation of the sweet substrate into an alcoholic beverage containing important nutritional components, including amino acids, proteins, vitamins and sugars. Consuming fermented foods daily may be equivalent to introducing new, albeit transient, microorganisms into the native gut microbiota (Papalexandratou et al., 2011).

Cereal-based fermented foods

Cereal grains are a major source of dietary nutrients worldwide. Although cereals are deficient in certain elements such as essential amino acids), fermentation is the simplest and most economical way to improve their nutritional value and sensory properties (Blandino et al., 2003). Traditional cereal-based foods consumed in World are processed through the natural fermentation of maize, sorghum, millet, and rice.

Traditional millet-based fermented foods

Baca

'Baca' is a traditional fermented food made from millet, which is consumed in Côte d'Ivoire as breakfast by adults and as a supplementary food for young children. The millet granule or corn flour is sieved, mixed with a quantity of water and rolled by hand to obtain a granulated product that can be fermented overnight at room temperature.

Wômi

It is a traditional dish based on sorghum, corn or millet flour obtained by frying. The cereal flour is added to boiling water and cooked by gelatinization, then left to cool before being mixed with flour. The resulting dough, whether or not inoculated with baker's yeast, is left to ferment overnight (Sahoré et al., 2007). Fermentation of millet leads to a decrease in oligosaccharides and indigestible polysaccharides lead to an increase in lysine content (Blandino et al., 2003). Likewise, an increase in methionine and tryptophan content has been observed during maize fermentation. Some amino acids can be synthesized and vitamins B bioavailability increased. Fermentation promotes optimal pH for the enzymatic degradation of phytates that are present in cereals in forms complexed with proteins and certain minerals such as iron, zinc and magnesium (Nyanzi and Jooste, 2012). Antinutritional factors such as phytates and tannins are among the constituents of the grain walls of cereals. Antinutritional factors contribute to malnutrition and reduced growth rate and are responsible for low protein digestibility, reduced bioavailability of mineral elements such as phosphorus, calcium, magnesium, iron and zinc and the reduction of certain enzymatic activities such as trypsin, alpha amylase and beta-galactosidase.

Indigenous rice-based fermented foods

Idli

A fermented, thick suspension made of a blend of rice (*Oryza sativum*) and dehulled black gram (*Phaseolus mungo*) is used in several traditional foods in Southeast Asian countries. Among them, idli and dosa are very popular in India and Sri Lanka (Sands and Hankin, 1974). Traditionally, for idli preparation the rice and black gram are soaked separately. After draining the water, rice and black gram are grinded independently, with occasional addition of water during the process. The rice is coarsely ground and the black gram is finely ground. Then the rice and the black gram batters are mixed together (2:1ratio) with addition of a little salt and allowing to ferment overnight at room temperature (about 30°C). Finally, the fermented batter is placed in special idli pans and steamed for 5–8 min (Nagaraju & Manohar, 2000).

Dosa

It is very similar to idli batter except that the rice and black gram are finely ground and that the fermented suspension instead of being steamed is heated with a little oil, on a flat plate. A dosa suspension is prepared by grinding wet rice and black gram separately with water. The two suspensions are then mixed and allowed to undergo natural fermentation, usually for 8–20 h. To make a dosa, the fermented suspension is spread in a thin layer (of 1–5 mm thickness) on a flat heated plate, which is smeared with a little oil or fat. A sol to gel transformation occurs during the heating and within a few minutes, a circular, semi-soft to crisp product resembling a pancake, ready for consumption is obtained (Battacharya & Bhat, 1997).

Traditional wheat-based fermented foods

Soy sauce

Soy sauce is a dark brown liquid, made from a blend of soybeans and wheat that is mainly used as an allpurpose seasoning in Japan, China and the Far East countries. Soy sauces have a salty taste, but are lower in sodium than traditional table salt. The traditional manufacturing techniques for soy sauce have been well described (Beuchat, 1983). Cooked soybeans are mixed with coarse wheat flour, with adjustment of the initial moisture of the mixture to about 55% (w/w). The soybean–wheat mixture is inoculated by molds, and after 3 days of fermentation at 25–35 C, the soybeans and

Ogi

Ogi is made by lactic acid fermentation of corn but sorghum and millet are also added for fermentation. Sometimes soybeans may add to improve its nutritive value. It is considered a popular food for infant in West Africa although it is also consumed by adults (Blandino et al., 2003). For the preparation of Ogi, the cereal grains are steeped in earth ware or enamel pots for 1–3 days. Lactic acid bacteria, yeasts and moulds are responsible for the fermentation although Lactobacillus plantarum is the predominant microorganism. Other bacteria such as Corynebacterium and then yeasts of the Saccharomyces cerevisiae and Candida species also improve the flavour. Ogi is sour porridge with a flavour resembling yoghurt. The colour of Ogi depends on the cereal grain used: cream-white for maize, reddish brown for sorghum, and grey for millet (Blandino et al., 2003).

Pozol

Pozol is a fermented maise dough with the form of balls of various shapes and sises. It is consumed in South-eastern Mexico by Indians and Mestizo groups, for whom it can be a main component of the daily diet. To prepare it, maise grains are boiled in limewater and coarsely ground. The resulting dough is kneaded to form a compact ball that is wrapped in banana leaves. It is left at ambient temperature from a few hours to several days or even more than a month. A complex microbial community that is incorporated mainly during the grinding procedure ferments the dough (Nanson & Field, 1984; Wacher, 1993). *Lactococcus lactis, Streptococcus suis, Lactobacillus plantarum, Lactobacillus casei, Lactobacillus alimentarium, Lactobacillus delbruekii* and *Clostridium sp*. as well as yeasts have been identified in pozol (Nuraida et al., 1995; Díaz-Ruiz et al., 2003).

Traditional sorghum-based fermented foods

Injera

Injera (Enjera) is the undisputed national food of Ethiopians. It can be made from different cereals, including sorghum, tef, corn, finger millet and barley, although tef (Eragrostis tef) is the major cereal ingredient in Ethiopian injera. To make injera the grains are dehulled manually or mechanically and milled into flour. This flour is mixed with water to form a dough, the starter (ersho) is added, and the dough is fermented for 2 or 3 days. The starter is a fluid saved from previously fermented dough mostly composed of lactic acid bacteria (Neela & Fanta, 2020). After fermentation the dough is thinned down to a thick batter and poured onto a lightly oiled pan, which is then covered with a tightly fitting lid to retain the steam. Within about 2–3 min it is ready to be removed from the pan and then is placed on a basket. The storage period does not usually exceed 3 days at room temperature (Blandino et al., 2003).

Kisra

Kisra (Aseeda or Aceda) is similar to injera and it is consumed throughout the Arabian Gulf, Sudan and Iraq. Kisra is make from a fermented dough of sorghum (Sorghum bicolor) or pearl millet flour (Sushma et al., 1995). The fermented dough is baked into thin sheets and it is eaten with certain types of stew prepared from vegetables and meat. Lactic acid bacteria are the main microbiota involved in this food fermentation (Adebo, 2020). flour mixture (known as koji at this stage) is immersed in a brine solution (22–25%, the ratio of koji to brine is about 1:3 w/v). After mixing, the salt concentration of the mixture usually falls around 18–21%. This brine solution containing koji is known as moromi. The moromi is left to ferment for a period of 1–12 months; the longer the fermentation time the better the soy sauce quality. After the moromi fermentation is completed, the liquid part (soy sauce) is separated, filtered, pasteurised and bottled (Mensah, 1997). Grains are boiled until soft, dried, milled and sieved in order to remove the bran. Milk is separately soured in a container, concentrated and mixed with the moistened wheat flour. The milk undergoes a lactic fermentation and the resulting paste is dried to a moisture content of 10–13% and then ground into a powder. The product is stored in the form of dried balls, brownish in colour with a rough surface and hard texture.

Tarhana

Tarhana (Trahanas) is a Turkish fermented food, prepared by mixing wheat flour, sheep milk yoghurt, yeast and a variety of cooked vegetables and spices (tomatoes, onions, salt, mint, paprika) followed by fermentation for 1–7 days (Ozdemir et al., 2007). The fermented matter is dried and stored in the form of biscuits (Campbell-Platt, 1994). The fermentation process and the type of product obtained is very similar to kishk. The sheep milk yoghurt contains Steptococcus thermophilus and Lactobacillus bulgaricus as the major fermenting organisms (Economidou & Steinkraus, 1993). Tarhana has an acidic and sour taste with a strong yeasty flavour, and is a good source of protein and vitamins. While tarhana soup can be used as a part of any meal, it is often eaten for breakfast.

The practical nutritional importance of tarhana is the improvement of the basic cereal protein diet by adding dairy protein in a highly acceptable form. The low pH (3.8–4.2) and low moisture content (6–9%) make tarhana a poor medium for pathogens and spoilage organisms. In addition, tarhana powder is not hygroscopic and it can be stored for 1–2 years without any sign of deterioration (Haard et al., 1999).

Traditional corn-based fermented foods

Kenkey

Kenkey is a fermented maise dough eaten in Ghana. Kenkey can be prepared using two methods. In the first one, the maise grains are soaked in water at ambient temperature for 1–2 days, after which the water is drained before wet-milling the hydrolysed grain. The resulting maise meal is allowed to ferment spontaneously after the addition of water to produce a stiff dough (solid state fermentation). In the second method, the maise meal is strained to remove all chaff after the addition of a large volume of water, thus giving a smooth texture product. The mixture is allowed to ferment overnight. The water is discarded leaving a wet mash, which is used to cook porridge. The fermentation is dominated by a variety of lactic acid bacteria, particularly *Lactobacillus fermentum* and *L. reuteri*, though yeasts and moulds also contribute to flavour development. A mixed flora consisting of Candida, Saccharomyces, Penicillium, Aspergillus and Fusarium species were found to be the dominant organisms during the preparation of this product (Jespersen et al., 1994).

Doklu

Doklu' is produced after spontaneous fermentation of maize paste and consumed by the populations of southern and south-eastern Ivory coast. After washing, whole corn kernels are soaked in water for 2 or 3 days, crushed, mixed in water and allowed to ferment spontaneously for 24 to 72 hours (Brou et al., 2008).

Traditional cereal-based fermented beverages

There are several types of cereal-based fermented drinks produced around the world, which can be classified based on the raw materials used or the type of fermentation involved in the manufacturing process.

Alcoholic fermented beverages can be classified into wines and beers, while the great majority of non-alcoholic fermentations are souring, mainly lactic acid fermentations (Chavan & Kadam, 1989; Fleet, 1998).

Beers

The technology for production of European barley beer and the biochemical and microbiological changes that take place during malting, fermentation and subsequent processing and storage are well documented in the literature, and it is not the objective of this paper to give an in-depth description of the process. In Africa traditional beers differ from the western-type; they are often sour, less carbonated and have no hops. They are consumed unrefined, including unfermented substrates and microorganisms (Haggblade & Holzapfel, 1993).

Pito

Pito Pito is a fermented food prepared from Sorghum, Millet and Maize. It is popular in Ghana and Southern Nigeria. Saccharomyces spp. and Lactic acid bacteria play an important role in fermentation. It contains 3 % alcohol content (Badmos et al., 2014).

Sake

Sake (rice wine) is a traditional alcoholic beverage, prepared from rice, consumed particularly in Japan and China (Lotong, 1998). The rice is polished and steamed, and part of it is steamed and used to grow Aspergillus oryzae, which produces different types of enzymes required for sake brewing. The seed mash is traditionally obtained by natural lactic acid fermentation involving various aerobic bacteria, wild yeasts, lactic acid bacteria, and sake yeasts (Chavan & Kadam, 1989; Lotong, 1998). The Sake production process is also well described in the literature and will not be reviewed in this article in detail.

Bouza

Bouza is a fermented alcoholic wheat beverage known since the times of the pharaohs. It is a light yellow, thick, sour drink consumed mainly in Egypt, Turkey and in some Eastern Europe countries (Morcos, & Ell-Damhoughy, 1973). It is prepared by coarsely grinding wheat grains, placing a portion of them in a wooden basin and kneading them with water into a dough. The dough is cut into thick loaves, which are lightly baked. The remainder of the grains is moistened with water, germinated, dried, ground and mixed with the loaves of bread, which are soaked in water.

Chicha

Chicha is a fermented corn product widely consumed in South America (Steinkraus et al., 1993). Chicha preparation is a unique fermentation process in which, traditionally, saliva serves as the source of amylase for the conversion of starch to fermentable sugars (Escobar & Steinkraus, 1993). Yeasts, particularly S. cerevisiae, and bacteria of the genus Lactobacillus sp., Leuconostoc sp., Acetobacter sp. with various moulds such as Aspergillus sp. are the primary fermenting microorganisms in chicha (Haard et al., 1999; Vargas-Yana et al., 2020).

Mahewu

Mahewu (amahewu) is an example of a non-alcoholic sour beverage made from corn meal, consumed in Africa and some Arabian Gulf countries. It is an adult-type of food, although is commonly used to wean children. It is prepared from maise porridge, which is mixed with water. Sorghum, millet malt or wheat flour is then added and left to ferment (Odunfa et al., 2001). The fermentation is a spontaneous process carried out by the natural flora of the malt at ambient temperature (Gadaga et al., 2000). The predominant microorganisms in the spontaneous fermentation of the African mahewu belongs to Lactococcus lactis subsp. Lactis (Steinkraus et al., 1993). The industrial production of mahewu is successfully carried out in Zimbawe (Bvochora et al., 1999).

Boza

Boza is a colloid suspension, from light to dark beige, sweet, slightly sharp to slightly sour, non-alcoholic beverage consumed daily in Bulgaria, Albania, Turkey, and Romania. It is made from wheat, rye, millet, maise and other cereals mixed with sugar or saccharine (Hancioglu & Karapinar, 1997). Due to its pleasant taste, flavour, and high nutritional values, boza has become a very popular beverage consumed as everyday food by people of all ages.

Tchapalo

Cereals are often used to produce beverages such as sweet must and tchapalo (N'guessan et al., 2010). Tchapalo is obtained from the alcoholic fermentation of sweet wort from sorghum malt. It can also be produced from corn. malt or millet. This drink is also characterized by a short shelf life (3 days) and a quality that varies from one production to another (N'guessan et al., 2010). Tchapalo is highly prized by the Ivorian population (Aka et al., 2017 ; Assohoun et al., 2012). This drink has nutritional values that help improve the diet of consuming populations. In addition, therapeutic virtues are attributed to it because of its laxative, antimalarial and anti-haemorrhoidal properties (Aka et al., 2014). The microorganisms found in fermented cereals are *L. plantarum, L. fermentum, L. cellobiose, L. brevis, L. coprophilus, Enterococus sp, Pediococus sp., Leuconostoc sp. Pediococcus pentosaceus, P. acidilactici, L. fermentum, W. cibaria, L.* fermentum (Assohoun et al., 2012).

Tuber food (cassava)

Cassava (*Manihot esculenta Crantz*) is one of the most important tubers in tropical countries. In Côte d'Ivoire, cassava is the staple food of the indigenous populations in the south and the second most consumed food in the west and centre of the country. However, in spite of all these potentialities, cassava faces various problems, namely high toxicity due to the presence of cyanogenic glycosides and a short shelf life due to its high perishability. In addition, cassava roots are very low in nutrients, especially vitamins, minerals and protein (Essia et al., 2003). To overcome these constraints, the populations have developed various artisanal processing techniques, including fermentation, which leads to the production of several dishes such as fufu, gari, attiéké, placali, attoukpou, etc. (Amoa-Awua et al., 1996).

Gari

Gari a partially gelatinized (by toasting), free-flowing granular flour with a slightly fermented flavor and sour taste. Gari is now produces and consumes in West Africa, central Africa and east Africa. In West Africa, it is the most consumed and traded of all food products made from cassava roots. It is consumed either soaked in cold water or stirred in boiling water to make a stiff paste and consumed with choice soup. Garican be yellow (if fortified with red palm oil) or white, although gari from biofortified cassava is gaining popularity now. Seventy percent of cassava processed as human food is gari (Moslehi-Jenabian et al., 2010). Its wide consumption is attributed to its relatively long shelf life and its easy preparation as a meal. There are variations in the gari produced within the sub-region in terms of physical, chemical and sensory qualities. However, the processing method used in this manual captures all variations as much as possible. It also emphasizes precautions on unit operations that have implications on finished product quality and safety (Zhu et al., 2014).

Fufu

Fufu a food made from soaked fermented cassava. Fufu is a popular cassava food found in several African countries. The alternative names of fufu are foufou, foofoo, fulful, foutou, akpu, udep utim, farine, yakayeke, agbalima, water-fufu, according to Oyewole and Yemis 2003. Fufu is traditionally produced and marketed as a wet, pasty food product.

For the production of fufu, the preliminary operations units are similar to the gari one Cassava roots are then peeled, washed, cut into thick chunks of 20 cm long, and soaked in water contained in earthen ware pots or in a slow flowing stream. The fermentation takes about four to five days. During this period, the cassava roots ferment and soften, releasing HCN into the soak water. A characteristic flavor of retted cassava meal also is produced. The retted roots are disintegrated in clean water, sieved, and the starchy particles that go through the sieve are allowed to settle for about 3 to 4 hours. The water is decanted while the sediment is packed into a cloth bag, tied, squeezed, and subjected to heavy pressure to expel excess water. The resulting meal is rolled into balls and cooked in boiling water for about 30 to 40 minutes. The cooked mass is pounded in a mortar with a pestle to produce a paste, fufu that can be eaten with sauce, soups, or stew. Fufu is also sold to consumers in wet form in small units packaged in plastic or polypropylene bags or in ready to eat cooked form. The balls are boiled in water and the soft dough is produced (Bamidele et al., 2015).

Attiéké

Attiéké is an essentially flavour starchy food, produced from fermented cassava root, originally prepared and consumed exclusively by some ethnic groups from Côte d'Ivoire. Nowadays attiéké is consumed in many neighboring countries such as Burkina Faso, Béni, Togo, Mali, Senegal (Assanvo et al., 2006 ; Coulin et al., 2006). It is a steamed granular cassava meal ready-to-eat, couscouslike product, with slightly sour taste and whitish colour (Coulin et al., 2006). Attiéké is similar to akeyke, a Ghaneen cassava fermented food but has a slightly sour taste and is eaten with milk or meat or vegetables. To produce attiéké, cassava roots are peeled, cut in pieces, washed and grated. During grating the cassava mass is mixed with about 10% of a traditionally prepared inoculum and about 0.1 % palm oil. The inoculum is prepared by storing boiled cassava roots for three days in an unwashed jute bag previously used for inoculums preparation. The inoculated pulp is fermented overnight in covered bins. The fermentation softens the cassava mash and gives to this meals it characteristic flavour and texture (Firmin, 1995). After fermentation, the pulp is filled into bags and pressed for several hours. The pressed pulp is taken from the bags and squeezed through a sieve to obtain granules that are sundried and then cleaned to remove fibers and waste. The dried granules are steamed to produce attiéké, which is sold in small plastic bags as a ready-to-eat food. There is a difference in process then in the final product characteristic according to communities who produce it.

Placali

Placali is a cassava fermented food typically originates from Côte d'Ivoire. Placali is always consumed with sauc included generally both sources of protein (animal and vegetable). Fermented cassava flour are energizing food due certainly to its high carbohydrate content. Placali prepared from fermented cassava dough. Cassava roots are first peeled and washed. And, the pulp is shredded and fermented. The obtained cassava dough is crushed, diluted, screened and poured gradually into a pot containing hot water. Under the effect of the heat produced by the fire, starch gelatinizes. It becomes sticky and then solidifies. A spatula is usually used to knead the cassava paste to get placali, a brittle cassava paste (Yao et al., 2015; Kouamé et al., 2015) .

Lafun and efubo

Lafun is another cassava popular fermented food in West Africa (Nigeria, Benin, Togo, Côte d'Ivoire). Lafun is prepared by soaking cassava roots for three days. The roots are grated and allowed to sun dry. The product is then grounded into a very fine powder form. An estimated amount of boiling water is mixed into an estimated amount of lafun flour.

It is allowed to cook and turned constantly to prevent any lump formation and burning. Another cassava fermented flour similar to fufu is efubo. It is a cassava fermented dry flour commonly consumed in the western states of Nigeria (Uzogara et al., 1990). The production involves peeling of cassava roots, washing and cutting into chunks. The chunks are soaked in water in pots or at edges of stream and left for three to four days to ferment and soften. At the end of fermentation the softened chunks are dried under the sun for 2 days, ground and sieved to produce efubo'(Uzogara et al., 1990). Cassava roots to ferment after which they are peeled, dewatered, sundried, milled and sieved to yield lafun (Wakil and Benjamin, 2015)

Kokondé
Kokondé is also known as Kokonte, Crueira or Alebo (Oyewole and Yemisi, 2003). It is an Ivorian originates cassava fermented food. Kokondé is prepared with fermented cassava ships. Then, cassava roots are first processed into fermented chips by peeling and soaked for hours. After grinding (optional), the pieces are washed and dried in the sun. Thatched roofs or sheet metal are used for drying. Drying may take several weeks depending on the state of the sunshine. The obtained fermented chips are crushed, ground and sieved into flour. The flour is cooked in a shooting paste. Kokondé is consumed with a sauce (Quintson 2015).

Agbelima
Agbelima is a popular cassava fermented food in Ghana and Côte d'Ivoire. It also used as raw material in the preparation of a wide range of traditional cassava meals including banku, akple and kenkey and can easily be produced in larger quantities at a relatively low cost (Ellis et al., 1997). The production ofagbelima involves the use of atraditional inoculum, the kudeme. According to (Ellis et al., 1997) the main purpose for using this inoculum is for souring and improving the texture, color and flavor of the product. The cassava roots used for agbelima production are knife peeled and steeped in water for initial fermentation and then ground to paste (Amoa-Awua et al., 1996). The grated mash from obtained is inoculated with a proportional quantity of kudeme. The cassava paste is left to ferment for up to 2 days in polypropylene sackswithout the application of any external pressure on the sacks. The paste is then pressed. And the paste is removed from the sacks, crumbled or granulated, and then steamed (Rosales-Soto et al., 2016).

Attoupkou
Attoupkou Attoupkou is a popular food in the southeast of Côte d'Ivoire (Nevry et al., 2007; Yao et al., 2015). The cassava roots are first peeled and cut coarsely. The fibers are removed and then the tubers are washed and shredded to give cassava dough. obtained is fermented and drained during a night under stone bloks pressure. The fermented dough is sifted and dewatered using sieve to eliminate some of the fibers. A steaming in a steamer gives a sticky cake, the attoupkou which is then packaged (Soro Yao et al., 2013).

Bêdêkouman
Bêdêkouman is a cassava fermented food family located in Côte d'Ivoire. It production is mainly located among Aboure N'zima ethnic group in the Southeast part of the country. It is a white bread as food with 10 to 15cm as size packeted in Tomatococcus danielli leaves localy called attiéké leaves. Bêdêkouman can be stored at room temperature for 4 days (Koffi-Nevry et al., 2008). To produce bêdêkouman the fermented cassava mash is cooked, shelled and shaped into Tomatococcus danielli. It is eaten with vegetables, fish or meat.

Kapok pogari
Kapok pogari is a mid-western Nigerian food is similar to gariin preparation. The only difference is that the grated and fermented mass is not sieved before roasting. The resultant product has bigger particles. Kapok pogariis consumed with fish, coconut or meat (Soro-Yao et al., 2013).

Dumby

Dumby is a common traditional food in Liberia. The cassava's skin, coarse central fibers, and rind are removed and the boiled tubers are placed in a wooden mortar and beaten with a heavy pestle. As the mass becomes homogenous, the pestle produces a loud crack as it gets thicker. Dumby is normally eaten witha soup made from a variety of meat and vegetables (Raheem and Chukwuma, 2001). In Liberia, cassava is made into dumby, which is prepared by placing boiled cassava roots following pounding, the dumby is cut into pieces and put in soup supplemented with vegetables. The food is used to feed children because of its high protein content (Balagopalan, 2002).

Abacha

Abacha or Akpu-mmiri refers to wet cassava chips consumed as a popular snack in south-eastern Nigeria. To prepare abacha, the cassava root tubers are washed, peeled, boiled in water for about 1 h and cut into longitudinal slices or chips. These chips are steeped in water for l-2 days during which the water may be changed once or twice. At the end of the fermentation (during which the taste of the chips becomes almost bland), the chips are finally washed two or three times with fresh cold water. An alternative handling for long term storage is to dry the chips under the sun for several days (Balagopalan, 2002).

Several microorganisms are involved in cassava fermented foods fermentation. It include lactic acid bacteria, Bacillus strains, yeasts, moulds and some others organisms. Fermentation is one the processes use to reduce tannin and phytate content in cassava roots and leaves. Fermentation was found to reduce the phytate levels to a large extent. The fermentation time effect on phytate and tannin reduction is also evident. Their content in fermented food depends on the fermentation techniques used. The reduction of the phytate content level in cassava fermented food is due to enzymatic activity. This enzyme may be naturally present in cassava (Aloys and Hui Ming, 2006) or secreted by involved microorganisms. The reduction of phytate is more significant after 24 to 48 h of fermentation and decrease after 48 h.The drop of pH probably contributes to the slow breakdown of the phytate after 48h of fermentation. Ranhotra et al., suggested that inorganic phosphate might contribute to the inhibition of phytase enzyme activity in fermented doughs.

Fermentation also has been foundto be effective in reducing tannin, the other important anti-nutritive factor in cassava. Fermentation is one of the most used methods in food processing. It reduces significantly cyanide content in cassava fermented food, to improve flavour and aroma of fermented food and contribute to bio-preservation of fermented food. The cyanide reduction trough fermentation is due to the enzymatic activity of the associate microorganisms in cassava fermentation.

Traditional fermented fish

The conservation of fish in tropical countries remains a problem due to its highly perishable nature, the lack of adequate infrastructure for fresh conservation and the climatic conditions that favour its degradation within hours. Thus, various traditional techniques are used to limit post-harvest losses, particularly in West Africa where techniques such as drying, salting, smoking and fermentation are used individually or in combination for the conservation of fresh fish (Anihouvi et al., 2006). One of the most widely used artisanal fish preservation techniques in Africa remains fermentation. Various locally processed products such as adjuevan in Côte d'Ivoire (Kouakou et al., 2013), lanhouin in Benin (Anihouvi et al., 2005), guedj in Senegal (Fall et al., 2014) and momoni in Ghana, whose processes include salting, fermentation and drying, are offered to consumers. They are generally used as condiments or sometimes as major sources of animal protein to enrich the nutritional intake of local cereal-based foods. Research on these products has shown that the lack of standardization of production techniques was at the origin of the variability of their physico-chemical, microbiological and sensory qualities (Anihouvi et al., 2006; Dossou-Yovo et al., 2011; Anihouvi et al., 2012a; Koffi-Nevry and Koussémon, 2012; Kouakou et al., 2013).

Momoni

In Ghana one type of fermented fish product, momoni is popularly used as condiment for preparing sauces for the consumption of yam, cocoyam and apetum (boiled unripe plantain). For the preparation of momoni, different types of freshwater fish can be used; usually African jack mackerel (Caranx hippos) is employed. They can be scaled and gutted followed by washing in tap water and salting (294 - 310 g/kg) is done with the gill and gut regions being heavily salted. The fish are arranged in baskets covered with aluminium trays or jute bags and fermentation is allowed for 1 - 5 days. Before retailing, the fermented fish are washed in brine water, rubbed with salt and cut into small pieces. The cut pieces are sun- dried on a wooden tray in the open air for a few hours. Momoni is a solid product that is added to boiling stew consisting of ground red pepper, tomato, onion and little quantity of palm oil. The finished product is usually of low quality with a high salt concentration and deteriorates rapidly during retailing and storage (Sanni et al., 2002).

Lanhouin

A fermented fish product is processed by spontaneous and largely uncontrolled fermentation. Disadvantages of this type of fermentation are that very little control can be exercised over the fermentation process and the product is often of variable quality with inherent risks of quality defects. Samples of lanhouin processed from cassava croaker /cassava fish (Speudotolithus sp.) or Spanish mackerel/king fish (Scomberomorus tritor), widely used as condiment in Benin, Togo and Ghana, were purchased from processors and retailers in the processing sites and markets respectively, for product characterization (Anihouvi et al., 2006).

Guedj

Guedj is a Senegalese and Gambian traditional fermented fish product, used as flavoring agent and very appreciated by the local populations because of its exceptional flavor and taste. For Guedj processing, the raw fish is often dressed, salted and allowed to ferment for about 2 to 3 days, followed by the drying step during which, the salted and fermented fish is put on raised platforms for about 3 to 5 days. In another procedure, the raw fish is left overnight to ferment before salting for 12-24 hours and drying (Anihouvi et al., 2012).

Adjuevan

Adjuevan, a traditional Ivorian naturally fermented fish prepared from the Atlantic bumper Chloroscombrus chrysurus. This product is widely used and appreciated as a condiment in many types of flavourings and cuisines to season sauces for the consumption of yam, plantain, attieke, etc and not eaten as food fish because of the strong smell (Koffi Nevry et al., 2007; Koffi-Nevry et al., 2008; Koffi-Nevry et al., 2011). Adjuevan is a salted and fermented fish traditionally produced in the west coast of Ivory Coast at ambient temperature (28 - 30°C) following two traditional methods. First method of production took place in jars covered with plastics and stones for 5 days and second method followed the same fermentation process and then fish were dried on racks or nets for at least 10 days (Montet et al., 2012). However, the uncontrolled fermentation process of during adjeuvan production could lead sometimes to a product with variable qualities with occasional public health hazards as indicated by Anihouvi et al. (2006). Various authors have reported a large range of microorganisms involved in fish fermentation in African regions. According to Anihouvi et al. (2007) a large number of microorganisms are associated to the fermentation of Lanhouin. The predominant genus of Lanhouin are Bacillus spp. and Staphylococcus spp. Similarly to Lanhouin, various species of microorganisms including Bacillus, Lactobacillus, Pseudomonas, Pediococcus, Staphylococcus, Klebsiella, Debaryomyces, Hansenula and Aspergillus involve in the fermentation of Momone (Sanni et al., 2002). The predominant microbial populations associated with Guedj fermentation were Proteus spp. Shewanella putrefaciens, and Bacillus spp (Diop, 2008). Since the solid substrate fermentation of fish is usually an alkaline type, microorganisms such as Bacillus spp., Staphylococcus spp., Micrococcus spp, which constituted the predominant genera involved in Lanhouin, Momone and Guedj are expected. The presence of similar genera of microorganisms has been reported for various other fermented products obtained by alkaline fermentation. In contrast, The recent work carried out by Koffi-Nevry et al. (2011) on Adjuevan a fermented fish from Côte d'Ivoire showed that the fermentation is dominated by lactic acid bacteria, and the genera and species isolated and identified were Leuconostoc lactis, lactobacillus fermentum, *Pediococcus sp*. and *Streptococcus sp.*

Improvement of the fermentation process for food quality

Unlike fermented foods in developed countries where fermentations are mostly controlled, most fermentations are spontaneous in Africa. The spontaneous nature of fermentations leads to disadvantages related to the lack of process control. Indeed, the products obtained are of highly fluctuating quality and the duration of fermentation is long (Anihouvi et al., 2006; Kouakou et al., 2013; Fall et al., 2014). For a more efficient control of this stage, it is necessary to develop improvement methods such as the use of starters for better control of the fermentation process and standardization of the quality of the fermented product. Several authors have shown that the main microorganisms in products can be used as starter for improving the quality of the fermented product (Zaman et al., 2010). Starter cultures can be defined as concentrated microbial preparations consisting of one or more viable microorganisms, characterized by exceptional physiological and metabolic properties and capable of inducing desired changes in the final product (Holzapfel, 1997). The starters are used in particular for the fermentation of different types of food, vegetable (cucumber, beet, date, fruit juice, cassava, cocoa etc.) animal products (yoghurt, cheese, butter) (Rigaux, 2009). They not only preserve food but also give it a different flavour from the original product. It also allows better control of fermentation and standardization of the production process (Holzapfel, 2002).

In Côte d'Ivoire, Barry Callebaut has been running a project since 2013 to provide cocoa farmers with yeast starters that lead to a better chocolate flavour. The taste of chocolate can be considerably improved by adding starters during the fermentation of cocoa beans according to Barry Callebaut.

Studies conducted by Ouoba et al (2005) in burkina faso showed that soumbala treated with Bacillus sarters had improved sensory characteristics and was appreciated by the panelists.

Meals prepared from cassava are low in protein, fat and ash, with less fibre. Consumed without any other source of nutritional intake, these dishes could cause a nutritional imbalance. With this in mind, Essia et al (2003) undertook work to fortify "attiéké" with yeasts that could increase the protein (up to 10.5%) and ash contents, without significantly affecting the organoleptic qualities (Yéboué et al 2017).

In Brazil, Schwan, (1998) used a microbial cocktail composed of Saccharomyces cerevisiae, Lactobacillus lactis, Lactobacillus plantarum, Acetobacter aceti and Gluconobacter oxydans. It was noted an improvement of the organoleptic characteristics of chocolate with cocoa from controlled fermentation. Lefeber et al (2011) reported that Lactobacillus fermentum accelerated the fermentation process by producing metabolites such as organic acids and aromatic compounds.

Penia et al (2013) evaluated the effect of lactic acid bacteria by adding Lactobacillus plantarum to ferment cocoa in Indonesia. This addition resulted not only in an increase of the various germs and metabolites but also in the fermentation index of cocoa.
N'ga et al (2014) showed in Vietnam that the use of Lactobacillus fermentum had a beneficial effect on the quality of cocoa as the percentage of fermented beans was 98.43.
Moreira et al (2017) noted in Brazil that the fermentation process of cocoa was accelerated to produce a more aromatic chocolate by adding a cocktail composed of *Saccharomyces cerevisiae*, *Lactobacillus plantarum* and *Acetobacter pasteurianus*.
Cempaka et al. (2014) and Penia et al. (2013) suggested the addition of a starter *S. cerevisiae* var. Chevalieri and *Lactobacillus plantarum*, separately, can improve the fermentation index or in other words, can shorten the fermentation time. *S. cerevisiae* var. Chevalieri was chosen in particular, considering its pectinolytic activity that may improve pulp degradation (Schwan 1998). Leal et al. (2008) evaluated *Kluyveromyces marxianus*, another pectinolytic yeast, as starter culture and showed that resulted cocoa bean had better sensorial evaluation.

Conclusion

Fermentation play an essential role in conferring the required stability, safety and sensory properties of the food products. Fermented foods provides lot of health benefits to our body by consuming them. Fermentation not only improves sensory and nutritional characteristics but also reduces losses and preserves food. In world, there are a variety of fermented products. However, the quality of these different products is variable because of the fermentation that takes place spontaneously. The use of starter for fermentation control is essential in African countries, to improve and sanitize the quality of fermented products.

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