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Review

Synergistic microbial interactions between lactic acid bacteria and yeasts during production of Nigerian indigenous fermented foods and beverages

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ABSTRACT

Fermented foods and beverages are mainly consumed by the indigenous people of Africa and other developing countries. Traditional fermentation is an age-long means of preserving perishable foods especially when other methods of preservation are not available and/or not consistent. The main beneficial microorganisms that are responsible for the fermentation of African indigenous fermented foods and beverages are lactic acid bacteria and yeasts which may be present as microflora on the substrates or added as starter cultures. The understanding of the synergistic interaction between these microorganisms in the fermented food matrices result in improved nutrient availability, food quality, palatability, organoleptic properties, increased shelf life, safety, digestibility and also play beneficial roles in modulating host immune system thereby minimizing the risk of certain diseases.

1. Introduction

Fermentation is an ancient method of food processing and preservation (Hussain, 2018, chap. 11). It is a cheap means of preserving the quality and the organoleptic properties of the food especially when other methods of preservation are not available or consistent. Fermentation delivers to food desirable properties (i.e increased nutritional value, palatability) and extended shelf life (improved microbial stability and safety of the fermented foods for several days, months and up to years). This method of food production and preservation is of economic importance and is commonly practiced among the underdeveloped and developing countries of Africa as this has meet the challenges of food security in many region of Africa and are also affordable to the poor sector of the community, which directly addresses the problem of malnutrition, thereby leading to increased socio-economy level (Adesulu & Awojobi, 2014).

Fermented foods and beverages (FFB) are mainly consumed by the native people of Africa and other developing nations. Fermentation processes involved a complex microbiological interaction between different types of microorganisms (Sieuwerts, de Bok, Hugenholtz, & van Hylckama Vlieg, 2008). The main beneficial microorganisms that are responsible for the fermentation of indigenous foods are lactic acid bacteria (LAB) and yeasts which may be present as microflora on the raw materials/substrates or added as starter (Adesulu & Awojobi, 2014; De Vuyst, Harth, Van Kerrebroeck, & Leroy, 2016). The fermentation of cereal grains and cassava tubers to produce foods and beverages is indigenous to many countries in Africa.

Microorganisms in natural or controlled fermentation co-exist and interact with each other to produce quality end products. During the production of the traditional FFB, there is need to understand the consortium of the natural micro-biota at every stages of fermentation, this is important to the quality of fermented food produced as each microorganism performed specific role(s), also the type of interaction that exist between the predominant microorganisms (especially LAB and yeast) present in the food matrices are important to the food quality (Vieira-Dalodé et al., 2006; Olanbiwoninu & Odunfa, 2018). The occurrence of undesirable or pathogenic microorganisms during traditional fermentation may give product of inconsistent quality, therefore proper understanding of the activities and kinetics of the LAB and yeasts involved during fermentation processes is necessary in other to be able to identify and select strains with desirable functional characteristic which will guarantee quality and safety the fermented food products (Adesulu-Dahunsi, Jeyaram, & Sanni, 2018a; Adesulu-Dahunsi, Sanni, Jeyaram, & Banwo, 2017; Oguntoyinbo & Narbad, 2015).

The understanding of the synergistic interaction/effect between these microorganisms during fermentation results in the improvement of nutrient availability in foods, and also improves the palatability,

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Fig. 1. Nigerian indigenous fermented foods and beverages. (A) White *gari* (B) Yellow (C) *Fufu* (D) *Lafun* (E) *Ogi funfun* (F) *Ogi pupa* (G) *Ogi baba* (H) *Ogi jero* (I) *Eko* (J) *Iru* (K) *Ogiri* (L) *Owoh* (M) *Okpehe* (N) *Burukutu* (O) *Pito* (P) *Emu* (Q) *Kunun-zaki* (R) *Masa* (S) *Kokoro* (T) *Wara* (U) Fried *wara*. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

organoleptic properties, increasing food shelf life, and digestibility. The synergistic microbial relationship that co-exists between LAB and yeast species during production of African FFB with emphasis on Nigerian indigenous fermented foods (IFF) are reviewed.

2. Nigerian indigenous fermented foods and beverages

In Nigeria and other nations in Sub-Saharan Africa, IFF formed main dietary component of the citizenry, with some being used as infants weaning food, meals among adults or as refreshments. These foods play immense benefits on the health, nutrition and socio-economy status of the people (Adesulu & Awojobi, 2014). In Nigeria, several traditional FFB are produced at the household level, they include, fermented cassava tubers (*gari, fufu, lafun, abacha*), fermented cereals (*ogi, eko*), fermented condiments (*iru, ogiri, owoh, okpehe*), fermented dairy products (*nunu, wara*), alcoholic and non-alcoholic beverages (*emu*, *pito, dolo, burukutu, kunun-zaki, agadagidi*) and snacks (*masa, kokoro*). In the course of production of these foods, LAB and yeasts are predominantly involved during the fermentation processes. Examples of these fermented foods are presented in Fig. 1.

2.1. Fermented cassava tubers

i. ***Gari:*** *Gari* is popularly consumed among the population of Central and West Africa. It is produced by solid state fermentation of the cassava tubers. In Nigeria, *gari* is consumed either by soaking in cold water (eaten with sugar or roasted groundnuts) or as a solid (referred to as *eba*) made with hot water and taken with soup. It is a coarse flour with slightly sour taste and having white (white *gari*) or yellow (yellow *gari*) color (palm oil is added during processing of the yellow *gari*. Yellow *gari* is popularly called *gari-yibo*.
ii. ***Fufu:*** *Fufu* is a fermented food produced from cassava tubers. It is indigenous to people in the South-Eastern and South-Western part of Nigeria and is produced by submerged fermentation. The fermented slurry is cooked to form a thick paste and is usually eaten with soup. It is popularly called *akpu* by the South-Easterners.
iii. ***Lafun:*** *Lafun* also known as *elubo lafun* is widely consumed by the Yoruba's (South-West Nigeria). It is prepared by submerged fermentation, after fermentation and sun drying, it is milled into fine powdery form inform of flour. The flour is made into dough by adding it into boiling water and stirring, *lafun* is eaten with indigenous soup (*gbegiri* and *ewedu* soup).
iv. ***Abacha:*** *Abacha* is a popular snack food that is produced from cassava tuber. It is common among the people of South-Eastern Nigeria. *Abacha* is consumed with coconut or palm kernel/ground nuts

2.2. Fermented cereals

i. ***Ogi:*** *Ogi* is a mild acidic viscous gruel that is either produced from white maize variety (*ogi funfun*), yellow maize variety (*ogi pupa*), red sorghum variety (*ogi baba*) or millet (*ogi jero*). It is used as weaning foods and can also serves as breakfast beverages among adults. *Ogi* can be eaten with bean cake, sugar or milk. In Nigeria *ogi* as it is popularly called, is also known as *akamu,* or *koko* by the indigenous people.
ii. ***Eko:*** *Eko* (also known as *agidi*) is a cereal-based fermented food

produced from fermented maize (white and yellow varieties). The production process is similar to that of *ogi*, but the difference is in the cooking process, the fermented *ogi* cake is cooked for a longer period to gelatinized and form a smooth paste. It is wrapped in banana leaves and allowed to cool. It is usually consumed with

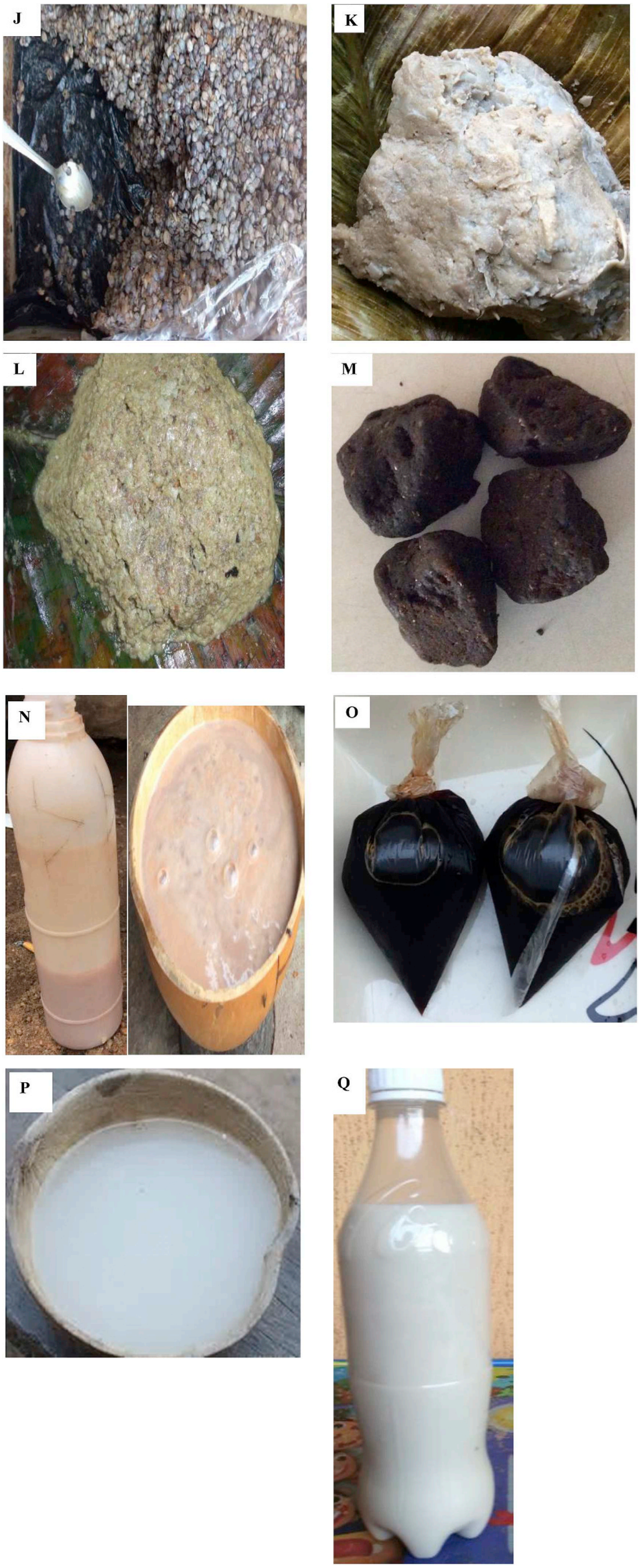

Fig. 1. (*continued*)

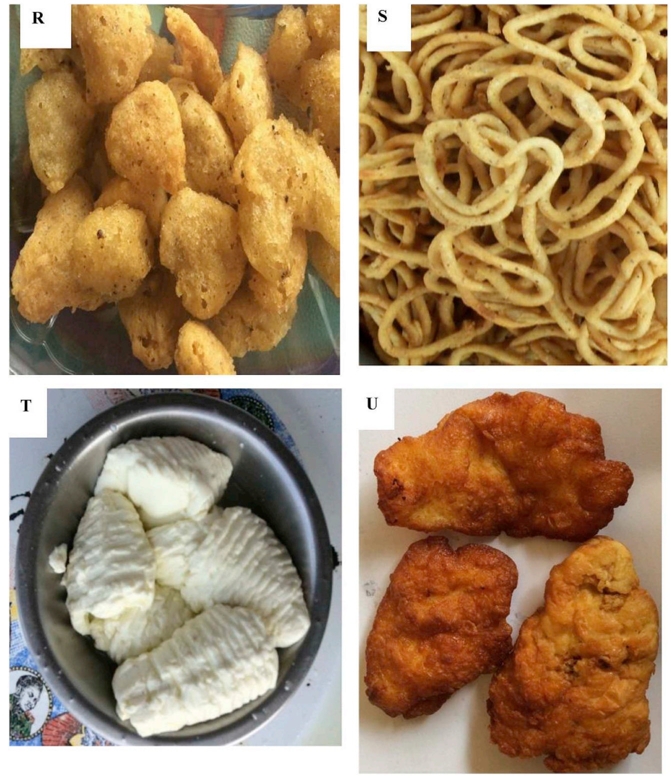

Fig. 1. (*continued*)

different indigenous stew and soup.

2.3. Fermented condiments

i. ***Iru:*** *Iru* (also called *dawadawa*) is a fermented condiment that is made from African locust beans (*Parkia biglobosa*). This condiment is rich in proteins, it is cheap and easily available in the markets. Because of the appealing aroma and taste when added to sauces and soups during cooking, it is sometimes used as a substitute for meat or fish by many low income earners or poor families. It is popularly hawked by the middle aged and elderly women in Nigerian markets in a calabash or wooden box. Many bacteria have been reportedly isolated from *iru* especially *Bacillus* sp. (Adewumi, Oguntoyinbo, Romi, Singh, & Jeyaram, 2014). *Iru* is of two different types; *iru woro* and *iru pẹtẹ*.
ii. ***Ogiri:*** *Ogiri* is produced from fermented melon seeds (*Cucumeropsis mannii*) or castor bean seed (*Ricinus communis*). It is not as popular as *iru* but is also consumed by the indigenous people. It is usually with unpleasant odour after fermentation, but when added to soup gives an appealing taste.
iii. ***Owoh:*** *Owoh* is a condiment that is produced by solid state fermentation of cotton seed (*Gossypium hirsutum*).
iv. ***Okpehe***: *Okpehe* is produced from leguminous oil seeds (*Prosopis africana*). It is popular in the South Eastern part of Nigeria.
v. ***Ugba:*** *Ugba* is an indigenous condiment that is popular in the Eastern part of Nigeria. It is prepared by solid state fermentation of African oil beans seed (*Pentaclethra macrophylla*), containing up to 44% protein content (Okechukwu, Ewelike, Ukaoma, Emejulu, & Azuwike, 2012).

2.4. Fermented dairy products

i. ***Nunu***: *Nunu* (popularly called *fura de nunu*) is an appetizing and refreshing fermented beverage from cow milk that is consumed with *fura* (millet flour compressed to balls) and granulated sugar. It has a sharp acid taste and is widely consumed in the Northern part of Nigeria. The milking process is done between the third and sixth months of lactating cows and it involves inoculating the fresh milk with a starter and allowing fermentation to take place for 24 h at room temperature. LAB and yeast are mainly isolated during *nunu* fermentation and each microorganism implicated gives characteristic flavor and taste.

ii. ***Wara:*** *Wara* is a traditional fresh milk product (curd) which may be eaten raw or fried in oil. Fried *wara* is used as meat and fish substitute by many indigenous people. It is hawked within walking distance of the Fulani's settlement, especially in the Northern part of Nigeria.

2.5. Alcoholic and non-alcoholic beverages

i. ***Emu:*** *Emu* (palm wine) is mildly alcoholic beverage that is made from palm sap. It is whitish in color and the fermentation process is dominated by *Saccharomyces cerevisiae*. It is popularly consumed in Nigeria and in some part of the West African countries. *Emu* is served during traditional marriage ceremonies or village meetings.
ii. ***Pito:*** *Pito* is an alcoholic traditional beverage produced from maize and sorghum grains. It is dark brown liquid drink and is popularly hawked and sold inside nylon by middle-aged women in many Nigerian markets.
iii. ***Burukutu:*** *Burukutu* is a fermented alcoholic beverage produced from sorghum grain with the alcohol content of about 4% (v/v) (Sanni, 1993). It is a light brown viscous liquid beer that is popularly sold in Mammi markets (market attached to Nigerian soldier barracks) and some part of the Northern Nigeria.
iv. ***Kunun-zaki:*** *Kunun-zaki* is produced from millet grains, blended with spices and water. It is non-alcoholic fermented beverage that is widely consumed in Nigeria at anytime of the day by all age groups.
v. ***Agadagidi:*** *Agadagidi* is alcoholic beverage produced from the fermentation of ripe plantains. *S. cerevisiae* has been reported to be involved in the fermentation (Sanni & Lonner, 1993). This indigenous beverage is popular in the South-Western part of Nigeria.
vi. ***Sekete:*** *Sekete* is an alcoholic beverage that is produced from fermented maize grains. *Sekete* beer is popularly consumed by the indigenous people in the rural communities of Western part of Nigeria (Sanni, 1988).

2.6. Fermented snacks

i. ***Masa:*** *Masa* (also known as *waina*) is a traditional fermented snack eaten with granulated sugar. It is produced from maize (*Zea mays*) or rice (*Oryza sativa*) and is popularly consumed in the Northern and Western part of Nigeria especially by the Muslims after Friday Jumat prayers (Sanni & Adesulu, 2013).
ii. ***Kokoro:*** *Kokoro* is a light brownish fermented snack that is produced from maize grain. It is popularly sold and consumed in South Western Nigeria.

3. Food and beverage fermentation by LAB and yeasts

LAB and yeasts have been reported as frequent groups of microorganisms involved during fermentation of Nigerian traditional FFB (Adesulu-Dahunsi, Sanni, & Jeyaram, 2017; Banwo, Sanni, Tan, & Tian, 2012). The most important bacteria during the fermentation process are the Lactobacillaceae; they produce lactic acid from carbohydrates (Amoa-Awua, Appoh, & Jakobsen, 1996; Kostinek et al., 2005). *S. cerevisiae* has also been reported as beneficial yeast in desirable food fermentation, it is an economically important microorganism that is commonly isolated during the fermentation processes. Yeasts are widely distributed in nature, they produce enzymes that are useful in food and chemical industries, and are also involved in the production of wine, sour dough bread and beer (Ogunsakin et al., 2017; Sanni & Lonner, 1993).

Lactobacillus sp., *Pediococcus* sp., *Streptococcus* sp., *Leuconostoc mesenteroides*, and *Weissella* sp. are dominant LAB species in the production of traditional FFB (Oyewole, 1997). Some yeast species including; *S. cerevisiae, Geotrichum candidum, Clavispora lusitaniae, Rhodotorula* sp., *Cephalosporium* sp., *Fusarium* sp., *Debaryomyces hansenii, P. camemberti, P. roqueforti, C. mycoderma, C. parapsilosis, Candida krusei, C. tropicalis, Galactomyces, C. parapsilosis, Galactomyces geotrichum, Pichia kudriavzevii* have also been isolated from these foods and *S. cerevisiae* are reported to be frequently involved in the fermentation of these foods (De Vuyst et al., 2016; Jespersen, 2003). Franz et al. (2014) reported that the most common LAB associated with traditional African FFB belongs to the genera *Lactobacilli* and *Pediococci*, with the predominance of *L. plantarum* and *L. fermentum* strains. Many African FFB have been investigated and the microflora responsible for the fermentation of these foods are mainly *Lactobacillus, Pediococcus, Leuconostoc, Weissella* and *Saccharomyces* species (Adesulu-Dahunsi, Sanni, & Jeyaram, 2017; Nwachukwu, Achi, & Ijeoma, 2010; Oguntoyinbo, Tourlomousis, Gasson, & Narbad, 2011).

Recently, LAB and yeasts were isolated from gluten free sourdough preparation from Nigerian sorghum flour, the LAB isolated includes; *Pediococcus* and *Weissella* species, while the dominant yeast species is *S. cerevisiae* (Ogunsakin et al., 2017). Adesulu-Dahunsi, Sanni, and Jeyaram (2017) identified LAB (*L. plantarum, P. pentosaceus* and *Weissella* sp.) as the predominant microorganisms during fermentation of Nigerian indigenous fermented foods (*gari, fufu,* and *ogi*). Yeasts have been reported to play essential roles in flavor improvement and acceptability of fermented cereal gruels (Jespersen, 2003). Mixed cultures of *S. cerevisiae* and *L. brevis* inoculated during controlled fermentation of cereals for the production *ogi* gives a product with appealing aroma (Teniola & Odunfa, 2001). Okagbue and Bankole (1992) and Odunfa and Oyewole (1997) reported the occurrence and dominance of *S. cerevisiae* during fermentation of traditional beverages. Padonou et al. (2009) also investigated the microbiology of fermented cassava for production of *lafun* and reported that *L. fermentum, L. plantarum* and *W. confusa* were LAB species isolated during the fermentation process, *Kluyveromyces marxianus, Pichia scutulata,* and *Hansenia guilliermondii* were also implicated. *L. plantarum* were reported to be commonly isolated LAB species during cassava fermentation for *gari* production (Adesulu-Dahunsi, Sanni, Jeyaram, et al., 2017; Kostinek et al., 2005). Microorganisms that are responsible for *masa* fermentation are *L. plantarum, L. fermentum* sp., *Pediococcus* sp. and *S. cerevisiae* (Oyeyiola, 1990; Sanni & Adesulu, 2013). Oranusi and Dahunsi (2015) also isolated genera *Aspergillus, Rhizopus, Penicillium, Fusarium, Cephalosporium, Alternaria, Bacillus, Klebsiella, Staphylococcus, Lactobacillus, Pseudomonas, Proteus* and *Enterobacter* during fermentation of maize for production of *kokoro* snack.

To ensure consistency in the food quality, well characterized autochthonous LAB and yeast isolates of food origin can be employed as starter cultures during controlled fermentation. Table 1 show the LAB and yeasts species that are involved in the fermentation of many Nigerian IFFs.

The specific roles played by LAB and yeasts during fermentation may lead to the development of novel food and beverages that is developed through simple fermentation technology, which may also directly affect the functional and sensory properties of the food end products. During food fermentation, LAB and yeast strains have being reported to contribute to food functionality (Jespersen, 2003; Ogunremi, Agrawal, & Sanni, 2015). Ogunremi et al. (2015) developed cereal-based functional food from cereals (the cereal mix contained; pearl millet, sorghum, and wheat grains) by fermenting the mix with probiotic strain *Pichia kudriavzevii* OG32. Increase in the developing and characterizing probiotics (mainly LAB and yeast species) will enhances it possibilities for health claim/uses and will be useful in starter culture selection and also for the production of nutraceuticals which create functional foods with increased bioavailability of nutrients

Table 1
Lactic acid bacteria and yeasts involved in the fermentation of Nigerian Indigenous fermented foods.

Raw Substrates	Types of food	Fermented Product	LAB and Yeasts involved	Ref.
Cassava tubers	Main meal	*Gari* *Fufu* *Lafun*	L. plantarum, L. cellobiosus, L. brevis, Lc. lactis; Leuc. mesenteroides, L. bulgaricus, L. buchnerri, Candida sp., Streptococcus sp, Geotrichum candidum, Klebsiella sp.*, Micrococcus luteus*, Corynebacterium manihot*, Aspergillus sp. *, Bacillus sp. *	Odunfa & Oyewole, 1997; Kostinek et al., 2005; Banwo et al., 2012.
Grains; Maize, Sorghum, Millet	Beverages	*Ogi*	L. plantarum, L. fermentum, *S. cerevisiae*, Candida krusei, L. pantheris, L. vaccinostercus, Lc. raffinolactis, P. pentosaceus, L. suebicus, L. brevis, S. lactis, Candida krusei, Clavispora lusitaniae, Rhodotorula sp., Corynebacterium sp.*, Enterobacter sp.*, Cephalosporium sp.*, Fusarium sp.*, Penicillium sp.*, Aspergillus sp. *	Odunfa & Adeleye, 1985; Teniola & Odunfa, 2001; Teniola et al., 2005; Oguntoyinbo et al., 2011.
Maize	Snacks	*Masa*	L. plantarum, P. acidilactici, L. fermentum, *S. cerevisiae*.	Oyeyiola, 1990; Sanni & Adesulu, 2013.
		Kokoro	Cephalosorium sp., Lactobacillus sp., Aspergillus sp. *, Rhyzopus sp. *, Penicillumi sp. *, Fusarium sp. *, Bacillus sp. *, Klebsiella sp. *, *Staphylococcus aureus**, Pseudomonas sp.*, Proteus sp. *, Enterobacter sp. *	Oranusi and Dahunsi (2015).
African locust bean	Condiments	*Iru*	B. subtilis*, B. pumilus*, B. licheniformis*, B. megaterium*, S. epidermidis*	Odunfa, 1981; Adewumi et al., 2014; Olanbiwoninu & Odunfa, 2018.
Melon seeds		*Ogiri* (*Ogiri-egusi*)	Pediococcus, B. subtilis*, B. megateruim*, B. firmus*, Proteus sp. *, Alcaligenes sp. *, *Pseudomonas aeruginosa**	Raheem, 2006; Olanbiwoninu & Odunfa, 2018.
African yam beans		*Owoh*	B. subtilis*, B. licheniformis*, B. pumilis, Staphylococcus sp. *	Sanni and Ogbonna (1991)
Soya bean		*Okpehe*	B. subtilis*, B. Iicheniformis*, B.megaterium*, S. epidermidis*, Micrococcus sp. *	
African oil beans		*Ugba*	Bacillus subtilis*, Staphylococcus sp. *, Micrococcus sp. *, Corynebacterium sp. *	Odunfa & Oyeyiola, 1995; Okechukwu et al., 2012.
Cow milk	Nigerian cheese	*Wara*	L. plantarum, Lactococcus sp., Streptococcus sp., Pediococcus sp., Leuconostoc sp., Lc. lactis subsp. cremoris, Lc. lactis subsp. lactis, L. delbrueckii subsp. delbrueckii, L. delbrueckii subsp. lactis, *L. helveticus*, L. casei, S. thermophilus, E. durans, E. faecium, Staphylococcus sp. *, Brevibacterium linens*, Propionibacterium freudenreichii*, Debaryomyces hansenii*, Geotrichum candidum*, Penicillium camemberti*, P. roqueforti*, Propionibacterium sp.*	Odunfa (1981).
Palm sap	Beverages	*Emu*	*S. cerevisiae*, Geotrichum candidum, Candida sp.	Sanni, 1988; Sanni & Lonner, 1993.
Sorghum, millet		*Pito*	Lactobacillus sp., Geotrichum candidum, Candida sp., Penicillum sp. *, Rhyzopus oryzae*.	Ekundayo, 1969; Glover, Abaidoo, Jakobsen, & Jespersen, 2005.
		Burukutu	Lactobacillus sp., Leuc. mesenteroides, *S. cerevisiae*	Achi, 2005; Ogunbanwo, Adewara, & Fowoyo, 2013.
		Kunun-zaki	L. plantarum, L. fermentum, Lc. lactis, L. pantheris, C. mycoderma, *S. cerevisiae*, Corynebacterium sp.*, Rhodotorula sp., Cephalosporium sp. *, Fusarium sp.*, Aspergillus sp*., Penicillium sp.*, Enterobacter sp. *.	Teniola et al. (2005)
Ripe plantain		*Agadagidi*	*S. cerevisiae*, Leuc. mesenteroides, Lc. lactis, B. subtilis*.	Sanni and Oso (1988).
Cow milk		*Nunu*	L. fermentum, L. plantarum, *L. helveticus*, Leuc. mesenteroides, E. faecium, E. italicus, W. confusa, C. parapsilosis, *C. tropicalis*, Pichia kudriavzevii, *S. cerevisiae*, Galactomyces geotrichum*.	Okagbue & Bankole, 1992; Owusu-Kwarteng et al., 2012.

*Other groups of microorganisms (bacteria, fungi, and mould) that are not predominantly isolated from the indigenous FFB. *L.; Lactobacillus; Lc.; Lactococcus; Leuc.; Leuconostoc*.

(Toma & Pokrotnieks, 2006).

4. Roles of LAB in traditional foods and beverages fermentation

Fermentation of traditional foods and beverages is mainly carried out by LAB. Many researchers have reported that LAB are commonly isolated during fermentation of these IFF (Abdelgadir, Ahmed, & Dirar, 1998; Adesulu-Dahunsi, Sanni, & Jeyaram, 2017; Girum, Eden, & Mogessie, 2005; Oguntoyinbo & Narbad, 2015; Sanni & Adesulu, 2013). During lactic acid fermentation, LAB and their enzymes produced are used to convert fermentable sugars in the food substrate into primarily lactic acid. Because of their long and safe historical use in production of FFB, occurrence in foods coupled with their promoting positive health impacts, LAB are 'Generally Recognized As Safe' (GRAS) status for human consumption (Adesulu-Dahunsi, Sanni, & Jeyaram, 2017; Leroy & De Vuyst, 2004). They can utilize substrates, produce metabolites and also possess probiotic potentials. LAB causes rapid acidification of the substrates by producing organic acids and technologically important substances, such as ethanol, aroma compounds, bacteriocins, exopolysaccharides (Adesulu-Dahunsi, Sanni, & Jeyaram, 2018c; Adesulu-Dahunsi et al., 2018a, b, c, d; Adesulu-Dahunsi, Jeyaram, et al., 2018b), and thus enhances the food shelf-life and microbial safety. The roles played by LAB includes extending the shelf life and nutritional quality of FFB, treatment of acute infantile diarrhea, and their antimicrobial properties have been reported (Ogunbanwo, Sanni, & Onilude, 2003; Oguntoyinbo & Narbad, 2015).

Lactic acid fermentation enhances the shelf life of the fermented products, as they produce different antimicrobial metabolites during the fermentation process (Halm, Lillie, Sorensen, & Jakobsen, 1993). The metabolites such as organic acids produced initiate an acidic environment which makes it unfavorable for the growth of undesirable and pathogenic microorganisms (Nout, 2009). LAB can also produce other antimicrobial bioactive molecules, such as ethanol, hydrogen peroxide, diacetyl, and bacteriocins (Ananou, Maqueda, Martinez-Bueno, & Valdivia, 2007; Caplice & Fitzgerald, 1999). Lactic acid fermentation are used as a means of decreasing the antinutrients content (i.e phytate and tannins) in the FFB and thus improves the bioavailability of essential dietary minerals in food products (O'sullivan et al., 2010).

5. Roles of yeast in traditional foods and beverages fermentation

Yeasts in a mixed population with LAB have major impact on the quality, taste, texture, and flavor of the fermented food products. They are important functional microorganisms present in many indigenous FFB, they are employed in production of baker's yeast for leavening of bread, they are also involved during wine and beer fermentation. *S. cerevisiae* was among the first microorganisms to be designated 'GRAS' status, and the first genetically modified organism used for recombinant production of food and feed additives (Jespersen, 2003). Yeasts play very important roles during fermentation of traditional foods and beverages across Africa and the world at large.

The predominant yeast species associated with African IFF is *S. cerevisiae* (Jespersen, 2003), though few researchers have also isolated *Schizosaccharomyces pombe, S. japonicus, Candida castellii, C. fructus, C. intermedia, C. krusei, C. tropicalis, Geotrichum candidum, Hansenula anomala, Kloeckera apiculata, Pichia membraefaciens, P. ohmeri, Saccharomyces chevalieri, S. uvarum, Kluyveromyces africanus, Torulaspora delbrueckii* and *Rhodutorula grainis* (De Vuyst et al., 2016; Jespersen, 2003). Applications of yeasts includes; ethanol production, single cell protein (SCP), feeds, industrial enzymes, and metabolites. Many yeast strains possess functional properties which results in enhanced nutritional values. The main role played by yeast during fermentation of foods and beverages is the fermentation of carbohydrates which results in formation of alcohols and other aroma compounds (Janssens, De Pooter, Schamp, & Vandamme, 1992; Oh & In, 2009).

6. LAB-yeast synergistic interactions in fermenting food matrix

Many traditional FFB in Africa are produced by fermentation involving LAB or yeasts and/or mixtures of both. During food fermentation, microbial behavior of the yeasts and LAB can result in the production of health-improving metabolites. Lactic acid fermentation plays important and predominant roles in the production of these fermented foods. Many LAB and yeasts have been isolated during fermentation of cereal and non-cereal products and have greatly influenced the organoleptic and the final quality of the food produced.

The LAB found in food performs unique role in the conversion of the substrates (raw materials) into lacto-fermented foods. These LAB work together and pair up with beneficial yeasts (and other beneficial microorganisms if present in the fermenting food matrix). Nigerian IFFs are produced majorly by spontaneous fermentation and *S. cerevisiae* frequently co-exists with LAB thereby microbiological succession usually takes place in the food matrices. The presence of LAB and yeast in the fermenting matrix contributes to the product characteristics. The process involved during natural or controlled food fermentation is as a result of complex microbial interactions which may be symbiotic or synergistic. The microorganisms do not interact only with the fermentable substrate but also with each other which cause division of labor between the microbes (Aidoo, Nout, & Sarkar, 2006; Ayad, Verheul, Engels, Wouters, & Smit, 2001). They also exchange metabolites and molecular signals thereby each individual cell in the mixture responds to the presence of others in the fermenting food matrix (Smid & Hugenholtz, 2010). The microbial interaction and the successions of microorganisms involved during the fermentation process are associated with changes in the environmental conditions and raw material compositions (Keller & Surette, 2006).

Various researchers have reported the co-existence and synergistic association between LAB and yeasts in African traditional fermented products (Omemu, 2011; Smid & Hugenholtz, 2010). Traditional cereal-based fermentations are performed by synergistic interaction between LAB and yeast. Researchers have reported that the growth of yeast in fermented foods is favored by acidifying environment created by LAB. The growth of LAB is also stimulated by the presence of yeast, which can provide growth factors, such as vitamins and soluble nitrogen compounds. The major metabolic activities of these microorganisms during the fermentation of cereal based foods are acidification, flavor formation, and leavening. The co-existence and association between yeast species (*S. cerevisiae, R. graminis, C. tropicalis, G. candidum C. krusei*) and LAB (*L. fermentum, L. plantarum, L. brevis*) have been reported during fermentation dynamic of cereal for *ogi* production, with *L. plantarum* and *L. fermentum* being the dominant LAB species and *S. cerevisiae* as the dominant yeast species (Teniola, Odunfa, & Holzapfel, 2005).

Production of alcohol and aroma compounds by yeast gives a typical flavor to fermented products and also impact on the food quality and their nutritional value (Jespersen, Halm, Kpodo, & Jacobsen, 1994; Torner, Martinez-Anaya, Antuna, & Benedito de Barber, 1992). Some yeast species have been reported to possess amylolytic, protease and phytase activities, these functions contributes to breaking down fermenting dough and allow better access to the essential minerals present in the substrates (Okechukwu et al., 2012; Omemu, 2011). Omemu, Oyewole, and Bankole (2007) reported that yeasts isolated during fermentation of maize for the production of *ogi* secretes extracellular enzymes and also possess amylolytic activities which aids the breakdown of carbohydrates in food to simple sugars for the use of LAB. Olanbiwoninu and Odunfa (2018) studied the interactions between bacteria and yeasts during the fermentation of *iru* and *ogiri* condiments, and reported that the microorganisms involved formed a complex consortium. The behavior of the microorganisms based on the production of acids and metabolites which have effect on the proteolytic bacteria indicated either symbiotic or synergistic effects.

The significant decrease in pH and simultaneous increase in acidity observed during spontaneous fermentation of cereal grains for production of *ogi* and *kunun-zaki* when compared with the ones fermented with only LAB or yeast culture was attributed to the combined action of yeast and LAB (Nwachukwu et al., 2010). Lactobacilli are the most important organisms that produced acidity in maize fermentation (Sanni & Adesulu, 2013). These organisms have also been implicated as partly responsible for initiating acidification in fermenting maize dough (Halm et al., 1993).

S. rouxii and *S. cerevisiae* have been implicated as being partly responsible for the organoleptic properties of fermented maize (Annan, Poll, Sefa-Dedeh, Plahar, & Jakobsen, 2003). *S. cerevisiae* has also been reported to excite the growth of LAB, by providing essential metabolites such as pyruvate, amino acids and vitamins and they also utilized certain metabolites produced by LAB as their carbon sources (Akinrele, 1970; Gadaga, Mutukumira, & Narvhus, 2001). Several yeast species have been reported to have pectinase activity that could be of importance to other microorganisms during fermentation. Yeasts can influence the antioxidant capacity of fermented food products through increase in the phenolic contents (Wang, Wu, & Shyu, 2014). Research studies have shown that cereal fermentation leads to phytase-dependent dephosphorylation of phytic acid. The phytic acid chelates several nutritionally important minerals in food, thus its degradation result in accessibility of essential minerals (i.e iron, zinc, calcium, and magnesium). The phytase activity present in the cereals is activated during LAB acidification, thereby leading to desirable biochemical changes such as production of aromatic compounds, proteolytic and lipolytic activities (Lioger, Leenhardt, Demigne, & Remesy, 2007; Moslehi-Jenabian, Lindegaard, & Jespersen, 2010; Reale et al., 2004).

LAB and yeasts have also been implicated during the fermentation of many other non-cereal products like fermented cassava tubers (Amoa-Awua et al., 1996). *Lactobacillus* sp. and *L. mesenteroides* were initially isolated during fermentation of cassava tubers to produce *fufu* and *gari*, as the acidity of the fermenting tubers changes, they allow the *S. cerevisiae* to take it turn. The synergistic metabolic activities between LAB and yeast involved in certain food fermentation influence the nutritional and functional properties of foods. This has enabled the selection of strains with desirable properties for use as starter culture in production of functional fermented foods. During food fermentation, the result of fermentative activities and interaction between LAB and yeast gives the food end product desirable characteristics and has positively affect the nutritional quality, sensory attributes and shelf life of fermented foods. The isolated LAB species have been used, often in combination with yeast species, as starter cultures in controlled fermentation. In indigenous food fermentation processes, the complex activities performed by the microbial consortia could only be achieved because of the synergistic interaction between these organisms. Lactic acid production, rapid acidification, extended product shelf life, improved organoleptic characteristics amongst other functional, technological and probiotic properties can therefore be achieved with the combination of well characterized LAB and yeast species.

7. Safety considerations in traditional fermentation of foods and beverages

Fermented foods are valued by many cultures for their safety potentials and health benefits. These foods are produced at a pH level of 4.0 or lower, an indication that they are safe for human consumption. Fermented foods are generally considered safe because the lactic acid produced by LAB during the fermentation process inhibits the activities of spoilage bacteria and destroy any potential pathogens that may be present in the food, also the involvements and activities of LAB and yeasts during food fermentation or processing enables the conversion of perishable foods in their raw state to safe, edible and shelf-stable form, thus aids in food digestibility and production of more nutritious and palatable food that are of enormous importance to human health. Cases of food poisoning or foodborne infection rarely occur in traditional foods that are properly fermented. Though, menace of food spoilage and food borne diseases arising from improper production of foods are prevalent in many developing countries of Africa (Achi, 2005; Oyewole, 1997).

Food safety concern as per microbial contamination is a subject of paramount importance. However, some basic food safety practices must be ensured before, during and after food fermentation, these includes, hand washing, proper cleaning of food contact surfaces, containers, storage time which may affects the food texture. It is also important to understand the roles that each processing stages i.e. peeling, washing, grinding, dehydration, packaging, and fermentation play in the safety of the final product because fermentation cannot eliminate all food-related health risks, therefore this method of food preservation should not replace the practice of food hygiene principles. It should also be taken to consideration that during traditional household food fermentation process, adequate time must be ensured by mothers and the food processors for production of wholesome foods and beverages, care should be taken that no unjustified shortcuts are allowed, because lack of adequate fermentation time may have significant implications as regarding the food safety and nutritional quality of fermented foods, and may also limit the effectiveness of acidification by LAB.

Other food safety consideration that may arise from handling and processing of foods in order to avoid hazards and growth of pathogenic microbes should be safeguarded. Improvement of product safety can be achieved by application of Hazard Analysis Critical Control Point (HACCP) from the raw material stage to processing and consumption by adhering strictly to the principles of Good Manufacturing Practice (GMP) and Good Hygiene Practice (GHP) (WHO, 1995), which includes; identifying points where hazards might occur during food production and fermentation process and employing accurate preventive measures to avert these hazards from occurring. For example, in cassava processing, the tuber must be cut into smaller sizes so as to enable enzymatic degradation of toxic substance and residue present (cyanogenic glycosides). Another is the elimination of mouldy growth in raw cereal grains to avoid possible mycotoxin contamination and use of clean and safe water. Other possible ways of minimizing the risk associated with traditional FFB preparation and accelerating spontaneous fermentation processes may include acceleration of the fermentation process by back slopping or implementation of carefully selected multifunctional strains as starter or adjunct culture under hygienic conditions, development and use of well characterized probiotics strains exhibiting health-promoting properties for controlled food fermentation and production of functional foods (Ogunremi et al., 2015). Quick responsiveness to food safety by the traditional producers, food handlers and consumers will help in strengthening and enforcement of food standards and improved hygienic practices during food production and processing, which may lead complete eradication of foodborne illnesses.

8. Conclusion

Fermentation as a method of food preservation technology is of economic importance to many developing countries in Africa because it is easily affordable. The microorganisms responsible for the fermentation process are indigenously present on the substrates as microflora, or they may be added as starter cultures. The investigation of various IFFs of Africa showed that the fermentation majorly involved the activities of LAB and yeasts. Thus, the study of microbial interaction and the fermentation dynamics will help in optimizing the application and the performances of the microorganisms for improved food products, also adequate selection of LAB and yeast strains with suitable technological properties will lead to the development of appropriate starter cultures. Controlled fermentation can be encouraged for upgrading of the product quality and consistence.

Declaration of competing interest

Authors declare no conflict of interest whatsoever in this paper. All of us read and approved this submission.

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