

## **The Use of Lactic Acid Bacteria Starter Cultures during the Processing of Fermented Cereal-based Foods in West Africa: A Review**

<sup>1</sup>Amenan Anastasie Soro-Yao\*, <sup>1</sup>Kouakou Brou, <sup>1</sup>Georges Amani, <sup>2,3</sup>Philippe Thonart and <sup>1</sup>Koffi Marcelin Djè

<sup>1</sup>Science and Food Technology Unit, Nangui Abrogoua University, 02 BP 801 Abidjan 02, Côte d'Ivoire

<sup>2</sup>Wallon Center for Industrial Microbiology (CWBI), University of Liège, Bld du Rectorat 29-B40, B4000 Liège, Belgium

<sup>3</sup>Walloon Center of Industrial Biology, Bio-industry Unit, Gembloux Agro-Bio Tech, 5030 Gembloux, Belgium

**Abstrak:** Bakteria asid laktik (LAB) merupakan mikroorganisma primer yang digunakan untuk menapai makanan berasaskan jagung, sorgum atau sekoï yang diproses di Afrika Barat. Proses penapaian menyumbang kepada perubahan diingini dalam rasa, perisa, keasidan, pencernaan dan tekstur dalam bubur (*ogi, baca, dalaki*), doh (*agidi, banku, komé*) ataupun produk berbutir yang dikukus (*arraw, ciacry, dégué*). Sama dengan produk bijirin yang ditapai yang boleh didapati di Afrika, produk-produk ini terjejas dengan masalah kualiti yang tidak konsisten. Penggunaan kultur mula LAB semasa penapaian doh bijirin merupakan subjek yang semakin menarik perhatian dalam usaha memiawikan proses ini dan menjamin keseragaman produk. Walau bagaimanapun, penggunaan oleh unit pemprosesan secara kecilan ataupun perusahaan agro-makanan masih terbatas. Ulasan ini bertujuan untuk menggambarkan dan membincangkan isu-isu utama yang memberi kesan terhadap penggunaan kultur mula LAB semasa proses penapaian makanan bijirin di Afrika Barat.

**Kata kunci:** Bakteria Asid Laktik, Kultur Mula, Bijirin, Makanan Fermentasi, Afrika Barat

**Abstract:** Lactic acid bacteria (LAB) are the primary microorganisms used to ferment maize-, sorghum- or millet-based foods that are processed in West Africa. Fermentation contributes to desirable changes in taste, flavour, acidity, digestibility and texture in gruels (*ogi, baca, dalaki*), doughs (*agidi, banku, komé*) or steam-cooked granulated products (*arraw, ciacry, dégué*). Similar to other fermented cereal foods that are available in Africa, these products suffer from inconsistent quality. The use of LAB starter cultures during cereal dough fermentation is a subject of increasing interest in efforts to standardise this step and guaranty product uniformity. However, their use by small-scale processing units or small agro-food industrial enterprises is still limited. This review aims to illustrate and discuss major issues that influence the use of LAB starter cultures during the processing of fermented cereal foods in West Africa.

**Keywords:** Lactic Acid Bacteria, Starter Cultures, Cereals, Fermented Foods, West Africa

### **INTRODUCTION**

The traditional cereal-based foods that are consumed in West Africa are processed by the natural fermentation of maize, sorghum and/or millet and are

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\*Corresponding author: amenansoro@yahoo.fr

particularly important as weaning foods for infants and as dietary staples for adults. In terms of texture, the fermented cereal foods are either liquid (porridge or gruel), stiff gels (solid) or dry (fried or steam-cooked granulated products). The fermentation process is often carried out on small or household scales and are characterised by the use of simple, non-sterile equipment, random or natural inoculums, unregulated conditions, sensory fluctuations, poor durability and unattractive packaging of the processed products (Olanrewaju *et al.* 2009).

West African countries are experiencing rapid changes in their social and economic environments, which are associated with changes in food consumption patterns. In response to increasing rates of urbanisation, efforts are now geared towards developing small-scale facilities for the processing of fermented cereal foods, thus ensuring the quality of the finished product (Trèche *et al.* 2002). The modern large-scale production of fermented cereal-based foods is almost entirely dependent on the use of defined strains of microorganisms, which could replace the undefined strain mixtures traditionally used for the manufacture of these products (Klaenhammer & Fitzgerald 1994). The development and improvement of inoculants containing high concentrations of live microorganisms, referred to as starter cultures, is a subject of increasing interest in efforts to standardise the fermentation step. Many studies have focused on the characterisation of the microorganisms that are commonly used in the processing of these products (Halm *et al.* 1993; Hounhouigan *et al.* 1993; Lei & Jakobsen 2004; Vieira-Dalodé *et al.* 2007; Nwachukwu *et al.* 2010; Sawadogo-Lingani *et al.* 2010; Songré-Ouattara *et al.* 2010; Oguntoyinbo *et al.* 2011; Turpin *et al.* 2011; Adimpong *et al.* 2012; Oguntoyinbo & Narbad 2012; Owusu-Kwarteng *et al.* 2012; Ekwem 2014; Obinna-Echem *et al.* 2014). Such research has demonstrated that fermentation was natural and involved mixed cultures of lactic acid bacteria (LAB), yeasts and fungi. The lactic acid bacteria species identified included *Lactobacillus fermentum*, *Lactobacillus plantarum*, *Lactobacillus salivarius*, *Lactobacillus delbrueckii*, *Lactobacillus amylolyticus*, *Lactobacillus reuteri*, *Lactobacillus paraplantarum*, *Lactococcus lactis*, *Leuconostoc mesenteroides*, *Pediococcus acidilactici*, *Pediococcus pentosaceus*, *Streptococcus gallolyticus* and *Weissella confusa*. Species identification was performed using phenotypic tests such as cell morphology, sugar fermentation patterns and gas production from glucose, as well as molecular typing techniques, including pulsed-field gel electrophoresis, PCR-based methods and DNA sequencing. The use of isolated strains during cereal dough fermentation was reported to (1) minimise dry matter loss, (2) enhance control over the fermentation step, (3) enhance acid production or reduction in pH levels, (4) contribute to aroma and taste formation, as well as to increase the overall acceptability of the product and (5) enhance the nutritional quality of the product through the formation of preservative compounds or a reduction in mycotoxins, such as aflatoxins and fumonisins (Hounhouigan *et al.* 1993; Halm *et al.* 1996; Annan *et al.* 2003; Lardinois *et al.* 2003; Fandohan *et al.* 2005; Teniola *et al.* 2005; Agarry *et al.* 2010; Songré-Ouattara *et al.* 2010; Enwa *et al.* 2011; Ekwem 2014). Despite these results, the use of LAB starter cultures by small-scale processing units or small-scale industrial agro-food enterprises continues to be limited.

The industrial use of LAB starter cultures in the food industry depends on the concentration and preservation technologies employed, which are required to permit long-term delivery of stable cultures in term of viability and functional activity (Carvalho *et al.* 2003). Commercial starter cultures are supplied in concentrated form by freeze-drying, vacuum-drying, spray-drying, drum-drying, fluidised bed-drying or air-drying. The use of dried starter cultures has been shown to be of great benefit by small-scale processing units in Senegal (Lardinois *et al.* 2003; Totté *et al.* 2003), where spray-dried *L. plantarum* starter cultures facilitated a greater degree of control over millet fermentation and standardisation of *arraw*, *ciakri* or *cere* processing. The aim of this paper is to highlight the current knowledge on the microbiology of fermented cereal-based foods in West Africa and to examine the major issues that influence the use of LAB starter cultures during cereal dough fermentation.

### TRADITIONAL FERMENTED CEREAL-BASED FOODS IN WEST AFRICA

Traditional fermented foods prepared from millet, sorghum or maize are consumed in many West African countries. The majority of these products are consumed as beverages, or for breakfast or as snack foods, while a few are consumed as staples and used as child-weaning foods (Table 1). Generally, treatments such as drying, dehulling, washing, soaking, grinding and sieving are some of the steps applied during the processing of fermented gruels, whereas milling and sieving are required as pre-fermentation steps during the production of dry foods, such as bread. These cereal-based fermented foods can be classified based on either the raw cereal materials used or the texture of the fermented product.

Classification based on the raw cereal materials:

- (1) maize-based foods, e.g., *banku*, *kenkey*, *mawè*, *agidi*;
- (2) millet-based foods, e.g., *ben-saalga*, *dégué*, *arraw*, *dagnan*;
- (3) sorghum-based foods, e.g., *ogi*, *kunun-zaki*, *komé*, *gowé*.

Classification based on the texture of the fermented product:

- (1) liquid (gruel and porridges), e.g., *ogi*, *baca*, *ben-saalga*, *dalaki*;
- (2) solid (dough and dumplings), e.g., *kenkey*, *akidi*, *banku*, *komé*;
- (3) dry (baked, fried and steam-cooked granulated products), e.g., *arraw*, *dégué*, *masa*, *wômi*.

**Table 1:** Most common cereal-based fermented foods from West Africa.

Product name	Raw material used	Nature of use	Country of production	References
<i>Akidi (agidi)</i>	a	a	a, b	Olasupo <i>et al.</i> 1997; Obinna-Echem <i>et al.</i> 2014
<i>Akamu</i>	a	a	b	Nwachukwu <i>et al.</i> 2010; Obinna-Echem <i>et al.</i> 2014
<i>Aklui</i>	b	b	c	Mestres <i>et al.</i> 1999
<i>Arraw/cakryl cere</i>	c	c	Senegal	Broutin 2003; Ndiaye <i>et al.</i> 2008
<i>Baca</i>	Millet, rice or maize	d	d	Brou <i>et al.</i> 2008; Soro-Yao <i>et al.</i> 2013, 2014
<i>Coco-baca</i>	Millet and maize	b/d	d	Soro-Yao <i>et al.</i> 2014
<i>Banku</i>	b	a	a	Blandino <i>et al.</i> 2003
<i>Ben-saalga</i>	c	d	e	Guyot <i>et al.</i> 2004; Songré-Ouattara <i>et al.</i> 2010
<i>Dagnan</i>	c	a	d	Aboua <i>et al.</i> 1989
<i>Dalaki</i>	c	b	b	Blandino <i>et al.</i> 2003
<i>Dégué</i>	c	b	e	Hama <i>et al.</i> 2009
<i>Eko or pap</i>	c	b	b	FAO 1990; Olasupo <i>et al.</i> 1997
<i>Fura</i>	c	a/d/e	a/b	Owusu-Kwarteng <i>et al.</i> 2012
<i>Gowé</i>	d	e	c	Viera-Dalodé <i>et al.</i> 2007
<i>Kenkey</i>	b	a/d	a/b	Olasupo <i>et al.</i> 1996; Annan-Prah and Agyeman 1997; Blandino <i>et al.</i> 2003
<i>Koko</i>	a	b	a	Blandino <i>et al.</i> 2003; Lei and Jakobsen 2004; Adimpong <i>et al.</i> 2012
<i>Koko sour water/ Porridge koko</i>	a	d/b	a	FAO 1990
<i>Komé</i>	d	a	f	Ali and Djalé 2001
<i>Kunun-zaki</i>	Millet or sorghum	e	b	Olasupo <i>et al.</i> 2000; Blandino <i>et al.</i> 2003; Oguntinyinbo <i>et al.</i> 2011; Oguntinyinbo and Narbad 2012
<i>Masa</i>	Millet or maize	f	b	Ayo <i>et al.</i> 2008
<i>Mawè</i>	b	c	f/c	Hounhouigan <i>et al.</i> 1993, 1999
<i>Ogil ogi-baba</i>	a	b	b/a	Blandino <i>et al.</i> 2003; Oguntinyinbo <i>et al.</i> 2011; Oguntinyinbo and Narbad 2012
<i>Wômi</i>	c	f	d	Aboua <i>et al.</i> 1989; Soro-Yao <i>et al.</i> 2013

Notes: Data with the same letter within a column are identical.

Raw material used: (a) maize, sorghum or millet, (b) maize, (c) millet, (d) sorghum.

Nature of use: (a) dough as staple, (b) porridge as staple, (c) basis for preparation of many dishes, (d) porridge as weaning food, (e) beverage for many adults, (f) fried cake as staple for breakfast and snack item.

Country of production: (a) Ghana, (b) Nigeria, (c) Benin, (d) Côte d'Ivoire, (e) Burkina-Faso, (f) Togo.

### **Gruels and Porridges**

The fermented cereal porridges consumed in West African countries vary greatly in consistency, from stiff and dry (e.g., mashed potatoes) to thin gruels. The differences in consistency can be attributed to differences in the solids content (the proportion of flour/meal to water used in preparation, 8%–10% total solids), their preparation and the degree to which the starch has been hydrolysed. They are eaten with bean cake or other protein-rich foods. Acidic stiff porridges, such as *dalaki*, are made in Nigeria by sourdough fermentation (Blandino *et al.* 2003). *Ogi*, *koko*, *ben-saalga*, *baca* and *arraw*, for example, are generally consumed as breakfast by adults and used as weaning foods in Benin, Nigeria, Ghana, Burkina-Faso, Côte d'Ivoire and Senegal (Broutin 2003; Lestienne 2004; Brou *et al.* 2008; Soro-Yao *et al.* 2013, 2014).

### **Gels/dough and Dumplings**

*Akidi*, *akamu*, *banku*, *dagnan*, *fura*, *kenkey* and *komé* are popular types of dough and dumplings in West African countries and are produced mainly from millet, maize or sorghum grains blended with spices and water, with the resulting fermented slurry compressed into balls and cooked. The cooked dough balls can be broken up, made into porridge by mixing with yoghurt, fresh milk, sugar or water and consumed as a rather lumpy soup. In this mixture, milk is a source of protein, and the millet, maize or sorghum ball provide carbohydrates. The sour taste of the cooked dough balls is particularly suited for quenching thirst (Owusu-Kwarteng *et al.* 2012; Obinna-Echem *et al.* 2014).

### **Steam-cooked Granulated Products**

These products result from the agglomeration or granulation of moistened flour or fermented dough and are sometimes steamed and then dried. Examples include dishes such as couscous, *cere* or *cakry* in Senegal, *aklui* in Benin and *dégué* in Burkina-Faso. Such foods are distinguished by the fineness of particle size, the existence and the length of a fermentation step and whether an initial steaming is performed. Couscous, the finest and most common granulated product, is often fermented in Senegal (Broutin 2003). Granulated products of average size, such as *cacry* in Senegal and *dégué* in Burkina Faso and Mali, are used to make, for example, porridge from curdled milk. Granulated products of larger sizes are not cooked before drying. Their processing may include a fermentation step that is more or less similar to that of couscous, if the cereal grains used are washed before they are ground into flour, which is often stored overnight and then granulated. The granulated product is not parboiled before drying, and fermentation which takes approximately 30 hours, can occur at the beginning of the drying step (Broutin 2003).

### **Baked or Fried Products**

Millet or sorghum flour can be fermented to prepare many types of breads or cakes. Mixing their cereal flour with water makes a type of dough that can be fermented and then fried to make several types of cakes popular in West African countries (Nkama 1993). *Massa* and *wômi* are traditional fried cakes that are made from sorghum, maize or millet in Nigeria and Côte d'Ivoire, respectively

(Lestienne 2004; Soro-Yao *et al.* 2013). These cakes are consumed in various forms by people of all ages. A crisp, brown edge and a mildly sour taste are the desired attributes of *masa* (Ayo *et al.* 2008). Neither sorghum nor millet contain gluten proteins, so small amounts of wheat flour are added to the mix to produce yeast-leavened breads. The amount of wheat flour substituted varies depending on the quality of the wheat flour, the baking procedure, the quality of sorghum or millet flour and the desired product.

## **IMPORTANCE OF FERMENTED CEREAL-BASED FOODS IN WEST AFRICA: AN UPDATE**

### **Healthy and Safe Products**

Lactic acid fermentation enhances the shelf life of the fermented product, most likely because the diverse array of antimicrobial metabolites produced during the fermentation process (Nout 1994). These metabolites include many organic acids, such as lactic, acetic and propionic acids produced as end products, which create an acidic environment unfavourable for the growth of many pathogenic and food-spoilage microorganisms (Caplice & Fitzgerald 1999). In addition to acids, LAB can produce a range of other antimicrobial metabolites, including ethanol generated via the heterofermentative pathway, H<sub>2</sub>O<sub>2</sub> produced during aerobic growth, diacetyl formed from excess citrate-derived pyruvate and bacteriocins, which are ribosomally synthesised antimicrobial compounds (Diop *et al.* 2010). Lantibiotics, a special class of bacteriocins produced by LAB and other Gram-positives, have been widely studied. Nisin is a well-known lantibiotic produced by *Lactococcus lactis* and widely used as a food preservative. Its activity is based on the permeabilisation of the cytoplasmic membrane, leading to its depolarisation (Hyde *et al.* 2006). Plantaricin and pediocin are other bacteriocins distributed among *L. plantarum* and pediococci species (Diep *et al.* 2006; Wiedemann *et al.* 2006), respectively. An inhibition of *Escherichia coli* and *Staphylococcus aureus* species was observed during *ogi* fermentation with a bacteriocin-producing *Lactobacillus* (Olasupo *et al.* 1997) and after incubation with *Lactobacillus* species isolated from *akamu* (Ekwem 2014), respectively.

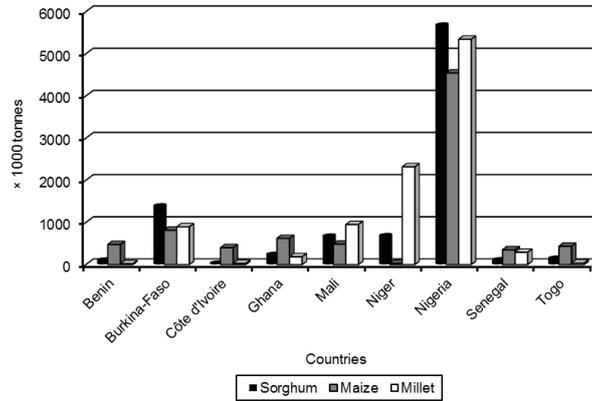
### **Probiotic and Prebiotic Potentials**

There is growing awareness in West Africa of the health benefits associated with probiotic foods. The term 'probiotic' refers to a product that contains mono or mixed cultures of live microorganisms, which, when ingested, improves host health by enhancing microbial balance [Food and Agriculture Organisation/World Health Organisation (FAO/WHO 2001)]. Most probiotic organisms used in human food belong to the genera *Lactobacillus* or *Bifidobacterium* (Herbel *et al.* 2013). *Escherichia coli* Nissle 1917, *L. lactis*, *S. thermophilus* and *Enterococcus faecium* are also often used as probiotics in human and animal nutrition. Recent research has shown that some fermented cereal-based foods available in West Africa may have probiotic potential. Based on laboratory trials, Lei and Jacobsen (2004) found that LAB isolated from *koko* can withstand the physiological challenges posed by the gastrointestinal tract (GIT) and may be able to colonise the GIT. In

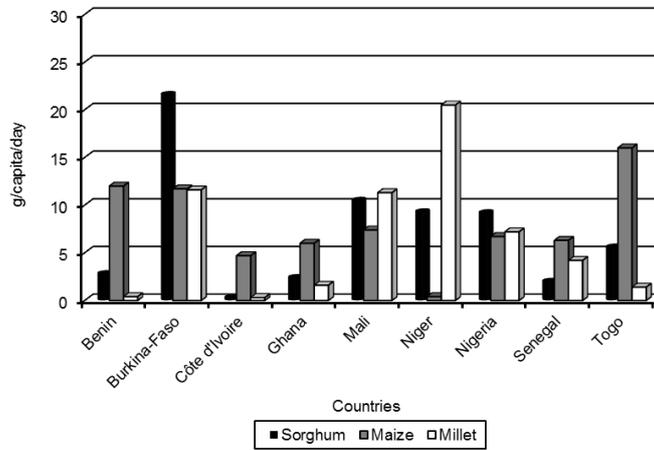
controlled human trials, Lei *et al.* (2006) demonstrated that *koko sour water* (KSW) reduces diarrhoea in children. Faecal enteric bacteria, such as *Salmonella*, *Shigella* and *E. coli*, were found to be significantly less prevalent in children fed fermented maize gruel than in children who were not (Mensah *et al.* 1991; Tetteh *et al.* 2004). A *Lactobacillus* starter culture was used to produce an improved *ogi* called DogiK, which exhibited antimicrobial properties against some diarrhoeagenic bacteria (Olukoya *et al.* 1994). The use of cereal constituents in probiotic food formulation as fermentable substrates for LAB starter cultures, encapsulation material, and/or dietary fibre supplementation have been explored (Venter 2007; Arena *et al.* 2014). Water-soluble and insoluble  $\beta$ -glucan, arabinoxylans, oligosaccharides and resistant starch are cereal indigestible but fermentable dietary carbohydrates, which are used to grow probiotic LAB and could be used to realise the beneficial effect of both the probiotic and prebiotic effects (Lamsal & Faubion 2009).

### Nutritional and Health Benefits

The products made from millet, maize or/and sorghum dough contribute to the protein requirements of West African peoples and are particularly important as weaning foods for children and as dietary staples for adults (Fig. 1, FAO 2012). Natural fermentation of cereals leads to a decrease in the level of carbohydrates, as well as some non-digestible poly- and oligosaccharides. Lactic acid fermentation also provides optimum pH conditions for enzymatic degradation of phytate, which is present in cereals in the form of complexes with polyvalent cations (such as iron, zinc, calcium, magnesium and proteins) (Coulibaly *et al.* 2011). The fermented gruel used as weaning food is usually inadequate in several nutrients, leading to widespread protein malnutrition during the weaning period (Ugwu 2009). Various attempts for nutrient restoration and supplementation of *ogi*, such as blending with fermented and unfermented legumes, adding pawpaw slurry at various levels of substitution (Otunola *et al.* 2006) and co-fermenting with cowpea (Oyarekua 2011), have been made. Additionally, the use of starter cultures to hydrolyse starch with the aim of increasing the energy value of cereal gruel was explored (Songré-Ouattara *et al.* 2009, 2010). Fermented cereal products have also been used as foods with enhanced health properties. Probiotic bacteria are able to change the population of the gut microbiota by influencing the metabolic and nutritional functions of commensal bacteria (Ciorba 2012). Indirect and/or direct immune modulating capacities of probiotic bacteria through antigen production, modulation of sensory motor functions, an enhancement of mucosal barrier functions and/or production of anti-pathogenic effects have also been reported (Ciorba 2012). *Lactobacillus pentosus*, *Lactobacillus brevis* and other probiotic bacteria were able to bind aflatoxin B1, the most potent mycotoxin among various aflatoxins, which may be formed during storage of cereal grains (Hamidi *et al.* 2013; Zoghi *et al.* 2014).



(a)



(b)

**Figure 1:** Millet, maize and sorghum's (a) food supply quantity or (b) protein supply, in 2009.

### USES OF LACTIC ACID BACTERIA STARTER CULTURES DURING CEREAL DOUGH FERMENTATION

Knowledge of the microbiology of fermenting cereal dough is essential for the development of starter cultures. The microbiology of many West African fermented cereal products – including the maize products *mawè*, *ogi* and *koko sour water* (Hounhouigan *et al.* 1993; Oguntoyinbo *et al.* 2011; Adimpong *et al.* 2012), the sorghum products *gowè*, *kunun-zaki* and *ogi-baba* (Odunfa & Adeyele 1985; Viera-Dalodé *et al.* 2007; Oguntoyinbo & Narbad 2012) and the millet products *arraw*, *ben-saalga* and *akamu* (Totté *et al.* 2003; Songré-Ouattara *et al.* 2008; Nwachukwu *et al.* 2010; Turpin *et al.* 2011) – have been examined. These

analyses have shown that the fermentation process is natural and involves mixed cultures of LAB, yeasts, fungi and *Bacillus* species. LAB species of the genera *Lactobacillus*, *Leuconostoc*, *Weissella*, *Streptococcus* and *Pediococcus*, as well as yeast species of the genera *Saccharomyces*, *Candida* and *Kluyveromyces*, have been identified as the dominant microorganisms in the fermentation process of cereal-based foods (Table 2). The isolated LAB species have been used, often in combination with yeast species, as starter cultures in controlled laboratory trials (Table 3). Overall, higher lactic acid production, rapid acidification, superior product shelf life, improved organoleptic properties and a greater degree of control over the fermentation process have been achieved with the use of starter cultures compared to traditional processes (i.e., without the use of a selected starter culture). Although many laboratory trials using LAB starter cultures have been undertaken, reports on fermented cereal-based foods produced with the identified and selected strains are extremely scarce. However, a collaborative project between Belgian cooperation and the Institute of Food Technology (ITA) in Dakar (Senegal) has been carried out in order to improve millet fermentation. In this research, spray-dried *L. plantarum* conditioned in millet flour was used as the starter culture during millet fermentation for *arraw* production. The project has led to the development of an improved processing of steam-cooked granulated products by small-scale urban processing units (Lardinois *et al.* 2003; Totté *et al.* 2003). Furthermore, this work showed that spray-drying was a cost-effective way of producing industrial-scale quantities of viable microorganisms and for long-term preservation of LAB starter cultures. The use of dried starter cultures could be of great benefit to the small-scale processing units in West Africa, considering the economic costs of and technical expertise required for production. A large majority of fermented cereal-based foods consumers in most West African countries are poor and disadvantaged, and as such, price, rather than food safety and quality, is their primary concern when purchasing food. In addition to economic considerations, the availability and the maintenance of the starter cultures could be suggested as another major factor; large quantities of starter cultures in active and pure forms are essential to the success of the fermentation stage of product manufacture. This can be achieved through the careful propagation of the inoculums. Propagation of starter cultures is time consuming, laborious, requires skilled personnel and is more prone to contamination, and necessitates significant investments in equipment (e.g., laboratory equipment, fermentors). Furthermore, contamination may occur during the process of culture production, which may result in poor growth of the LAB and defective products. Finally, dried starter cultures are easier to use and maintain, as they remain stable for up to two years (Brandt 2014).

**Table 2:** Predominant fermenting microorganisms of some cereal-based fermented foods from West Africa.

Lactic acid bacteria and other microorganisms	Source of isolation	Raw material used	References
<i>L. fermentum</i> , <i>L. reuteri</i> and <i>Candida</i> spp., <i>Saccharomyces</i> spp.	Kenkey or koko	a	Halm et al. 1993
<i>L. fermentum</i> , <i>L. reuteri</i> , <i>L. brevis</i>	Mawè	a	Hounhouigan et al. 1993
<i>P. acidilactici</i> , <i>W. confusa</i> , <i>L. fermentum</i> , <i>L. reuteri</i> , <i>L. salivarius</i> , <i>L. paraplantarum</i>	Fura	b	Owusu-Kharteng et al. 2012
<i>W. confusa</i> , <i>L. fermentum</i> , <i>L. salivarius</i> , <i>Pediococcus</i> spp.	Koko sour water	c	Lei and Jakobsen 2004; Adimpong et al. 2012
<i>L. plantarum</i>	Arraw, cere or cakry	b	Totté et al. 2003
<i>L. plantarum</i> , <i>L. pentosus</i> , <i>L. celibiosus</i> , <i>P. pentosaceus</i> , <i>L. mesenteroides</i>	Akamu	c	Nwachukwu et al. 2010
<i>L. acidophilus</i> , <i>L. delbrueckii</i> , <i>L. lactis</i> , <i>L. casei</i> , <i>L. fermentum</i> , <i>L. bulgaricus</i> , <i>L. plantarum</i>			Ekwem 2014
<i>L. plantarum</i> 4.4, <i>L. plantarum</i> 6.1, <i>L. fermentum</i> 11.11.2, <i>L. fermentum</i> 3.7, <i>L. fermentum</i> 7.4	Ben-saalga	b	Songré-Ouattara et al. 2008 ; Turpin et al. 2011
<i>L. plantarum</i> and <i>B. subtilis</i> <i>L. fermentum</i> , <i>L. plantarum</i> , <i>S. gallolyticus</i> subsp, <i>macedonicus</i> , <i>P. pentosaceus</i> <i>W. confusa</i>	Kunun-zaki	Sorghum or millet	Inyang and Dabot 1997 ; Oguntoyinbo et al. 2011; Oguntoyinbo and Narbad 2012
<i>L. fermentum</i> , <i>P. acidilactici</i> , <i>W. confusa</i>	Malted sorghum grains	d	Sawadogo-Lingani et al. 2010
<i>L. fermentum</i> , <i>W. confusa</i> , <i>L. mucosae</i> , <i>P. acidilactici</i> and <i>Kluyveromyces marxianus</i> , <i>Pichia anomala</i>	Gowé	d	Viera-Dalodé et al. 2007
<i>Lactococcus raffinolactis</i> , <i>Pediococcus</i> sp., <i>P. pentosaceus</i> , <i>L. plantarum</i> , <i>L. suebicus</i> , <i>L. brevis</i> <i>L. plantarum</i> , <i>L. brevis</i> , <i>P. pentosaceus</i> and <i>B. subtilis</i> , <i>Candida valida</i> , <i>Candida krusei</i> , <i>Geotrichum candidum</i>	Ogi	c	Teniola et al. 2005  Teniola and Odunfa 2002
<i>L. plantarum</i> , <i>L. pantheris</i> , <i>L. vaccinofermentum</i> <i>L. plantarum</i> , <i>S. lactis</i> and <i>C. krusei</i>	Ogi-baba	d	Oguntoyinbo et al. 2011 Odunfa and Adeyele 1985

Notes: Data with the same letter within a column are identical.

Raw material used: (a) maize, (b) millet (c) millet, maize or sorghum (d) sorghum.

## **FACTORS ENABLING THE DEVELOPMENT OF DRIED LACTIC ACID STARTER CULTURES FOR CEREAL DOUGH FERMENTATION**

Fermented cereal-based foods provide West African consumers with an affordable source of food and contribute to their food and nutritional security. Growing incomes and improved levels of education in urban centres across some West African countries are leading to changes in dietary habits and a wider variety of foods being consumed. As a result, fermented foods are no longer the main staples in many areas, but are still consumed as side dishes or condiments. Fermented foods offer many opportunities for diversification as a result of their global popularity; demand for many fermented cereal-based products is increasing worldwide, as they suit social and cultural culinary traditions in many parts of the world. Rural or urban dwellers are reassured that the product may be safer to consume than other food and beverages, as a result of fermentation. Increasing international travel due to globalisation has changed the eating habits of consumers across the globe. Moreover, export markets have expanded the potential consumer base for fermented foods beyond simply meeting the needs of developing countries. Markets catering to the growing international demand for niche and ethnic products are opening up as well. The need to assure the safety and quality of fermented food products for international consumers and the demand of West African consumers for safe, high-quality food have been driving forces for the development of agro-food processing companies in Africa. Several reviews have focused on the rapid evolution of the food-processing sector in West Africa (Trèche *et al.* 2002; Aworth 2008; Broutin & Subsol 2011). Small Agro-Food Industrial (SAFI) enterprises are positioned between the diffuse sector of the informal food processing micro-enterprises and the large-scale food industries. West African SAFI have evolved in tandem with the increasing urbanisation that is occurring in 15 West African countries [Economic Community Of West African States (ECOWAS 2014)] by their marginal food security and nutritional status. SAFI enterprises have two major functions, (1) to meet an increasing consumer demand for safe food products and (2) to improve the supply of nutritious food products that will aid in reducing public health problems, such as infant malnutrition, micronutrient deficiency and food safety. An increasing number of successful initiatives have been carried out in West Africa to improve the processing of fermented products. For example, in Senegal, Benin and Nigeria, millet, maize or sorghum requires short processing times, and products such as *arraw*, *cacry*, *cere*, *kunun-zaki*, *mawé* and *ogi* are now found in most markets and supermarkets in the form of vacuum-sealed packets (Trèche *et al.* 2002).

## **SELECTION CRITERIA OF DRIED LACTIC ACID BACTERIA STARTER CULTURES FOR CEREAL DOUGH FERMENTATION**

Technological effectiveness must be considered when selecting LAB strains for cereal fermentation. Selection criteria for LAB depend on the desired

characteristics of the final product, the desired metabolic activities, the characteristics of the raw materials and the applied technology.

### **Ability to Realise Fast Acidification and Production of Antimicrobial Compounds**

Food preservation by lactic fermentation relies on the removal of fermentable carbohydrates, the consumption of oxygen, the formation of organic acids and a concomitant decrease in pH. The immediate and rapid production of sufficient quantities of organic acids to reduce pH below 4.0 within 24 h of fermentation is an essential requirement of fermented cereal-based foods (Hounhouigan *et al.* 1993, 1999; Annan *et al.* 2003; Viéira-Dalodé *et al.* 2008). Lactic acid bacteria microbial antagonism could be attributed to the production of organic acids, ethanol, diacetyl, hydrogen peroxide or carbon dioxide, alone or in combination, and could further result from the production of bacteriocins (De Vuyst & Vandamme 1994). The rapid production of these compounds may contribute to the inhibition of pathogenic or spoilage flora and thus enhance the shelf life and microbial safety of the fermented product (Omemu & Faniran 2011; Okerere *et al.* 2012; Ekwem 2014).

### **Ability to Dominate the Indigenous Microbiota**

The ability of LAB to dominate the indigenous population during cereal dough fermentation is another important characteristic of a starter culture. The dominance of the starter culture would be exerted by its fast and predominant growth under fermentation conditions and/or its ability to produce antagonistic substances, such as bacteriocins. Huch *et al.* (2008) reported the use of molecular fingerprinting techniques e.g., Random Amplified Polymorphic DNA with Polymerase Chain Reaction (RAPD-PCR) and Pulsed-field Gel Electrophoresis (PFGE), to amplify the growth of a selected freeze-dried LAB starter culture during cassava fermentation for *gari* production.

### **Ability to Exert Probiotic Effects**

Human trials to test the tangible physiological/health benefits of LAB present a difficult challenge. In vitro studies could be used to examine potential probiotic characteristics, such as antimicrobial properties and survival in acids and bile, as well as lactic acid, hydrogen peroxide, biosurfactant and bacteriocin production (Bayane *et al.* 2006; Anukam & Reid 2009). In addition to these characteristics, potential probiotic lactic acid bacteria should adhere to the epithelial tissue, colonise the GIT, stimulate a host immune response, influence metabolic activities such as vitamin production and compete with pathogenic microorganisms, thereby preventing their survival in the GIT (Kalui *et al.* 2010). Probiotic bacteria prevent growth of pathogenic microorganisms through competition, exclusion and the production of organic acid and antimicrobial compounds. Acid and bile tolerance are two fundamental properties that demonstrate the ability of probiotic microorganism to survive passage through the upper gastrointestinal tract.

### **Ability to Improve the Nutritional Quality of the Fermented Food**

Millet, sorghum and maize have significant amounts of inositol hexaphosphates (IP6), referred to as phytic acid or phytates. Phytates have been recognised as antinutritional factors that affect the bioavailability of both major minerals, such as calcium and phosphorus, and trace minerals, such as zinc, iron, copper and manganese. In West African countries, the low bioavailability of minerals (e.g., iron and zinc) in cereal-based foods is a crucial problem for child nutrition (Camara & Amaro 2003). Other antinutrients of importance in cereal grains are tannins and  $\alpha$ -galacto-oligo-saccharides ( $\alpha$ -GOS) e.g., stachyose and raffinose. Decreasing the amount of phytic acid or tannins and metabolising stachyose or raffinose will be very helpful, due to their influence on the nutritional quality of cereal grains; thus, a phytase,  $\alpha$ -galactosidase or tannase producing LAB will be useful during cereal dough fermentation. In addition to these characteristics, the ability of LAB strains to bind mycotoxin such as aflatoxin, which may form during the storage of cereal grains, could be explored.

### **Ability to Hydrolyse Starch**

The use of amylolytic LAB to hydrolyse starch with the aim of increasing the energy density of cereal gruels could be explored (Songré-Ouattara *et al.* 2009). Amylolytic LAB may decrease the viscosity of bulk, starchy weaning gruel, which may improve nutrient density while maintaining an acceptable thickness for feeding young children (FAO/WHO 1995).

### **Ability to Have Good Stability during Production and Storage**

The stability of dried LAB refers to its viability and metabolic activity (acidifying activity). The suitability of LAB starter cultures for large-scale production and their stability during drying and long-term storage are important criteria for starter culture selection (Yao *et al.* 2009a). Cultures must be able to withstand large-scale fermentation, drying and long-term storage in the dried form. Proper packaging for long-term storage of dried cultures is important. The dried culture should contain more than 95% dry matter and be stored at low temperature (4°C), vacuum-sealed, and protected from light and moisture to avoid loss of viability and metabolic activity (Yao *et al.* 2008, 2009b; Coulibaly *et al.* 2009). To achieve health benefits, probiotic bacteria should be viable in the range of approximately  $10^6$ – $10^7$  cfu/g of product during consumption (Lamsal & Faubion 2009). Important factors such as pH, post-acidification, production of hydrogen peroxide, oxygen level, temperature, food matrix and interaction with the starter organisms affect LAB viability during refrigerated storage of fermented products (Dave & Shah 1997).

## **CONCLUSION AND FUTURE PROSPECTS**

Lactic acid fermentation contributes to the safety, health, organoleptic, technological and nutritional properties of fermented cereal-based foods of West Africa. The challenges here relate to the stability, reproducibility and productivity of fermentations. *L. fermentum*, *L. plantarum*, *L. salivarius*, *L. delbrueckii*,

*L. amylolyticus*, *L. reuteri*, *L. paraplantarum*, *Lact. lactis*, *Leuc. mesenteroides*, *P. acidilactici*, *P. pentosaceus*, *Str. gallolyticus* and *W. confusa* species have been identified in efforts to standardise the fermentation step. The use of LAB starter cultures has largely been restricted to laboratory applications and has not been transferred to industrial applications. Dried LAB starter cultures are easier to use and offer excellent possibilities for greater control over the fermentation process. The question “which starter culture technology for which production cost?” summarises the future directions for the application of dried starter cultures in West Africa. Careful selection of dried LAB starter cultures for cereal fermentation should take into account their ability to (1) realise fast acidification and produce antimicrobial compounds, (2) dominate the indigenous microbiota, (3) exert probiotic effects, (4) improve the nutritional quality of the fermented product, (5) hydrolyse starch, and (6) be stable during production and storage. To date, only a handful of studies have examined the health-related properties of West African fermented cereal-based foods and their potential use as probiotic foods. Fermented cereal-based foods offer opportunities to include probiotics, prebiotics and fibres into the diets of West African consumers (Lamsal & Faubion 2009). Millet, maize and sorghum grain represent examples of such opportunities. Cereal grain and cereal components could be used as probiotic carriers with the added advantage of providing healthful bioactive components and fibres. Furthermore, commitments to probiotics research and in vivo or in vitro trials of both identified and potential probiotic foods must be made and pursued, respectively.

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