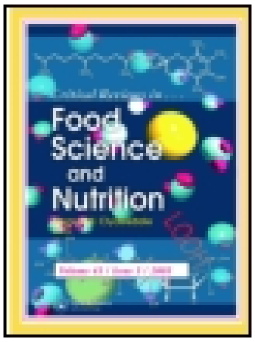

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Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value added products

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Abstract

With the prevalent food insecurity in Africa, there is a growing need to utilize the available crops to develop nutritious, affordable and palatable food for the populace. Millet is critical in this role, relative to its abundance in the continent and good nutritional composition. For ages, fermentation and malting have been traditionally used to transform millet into variety of produce. A paradigm shift has however occurred over the years, giving birth to new commercially available products. This review thus appraises and gives an overview of traditional and modern fermented and malted products. Although, millet has been diversified to several products, its major food uses are still restrained to traditional consumers and largely remains underutilized. Considering the potential embedded in this grain, it is important to explore this crop through the application of appropriate modern fermentation and malting technologies. This will ensure the availability of ready to eat (RTE) and ready to use (RTU) food products and to a large extent address the incessant food security challenges plaguing Africa.

Keywords

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Millet, fermentation, malting, food products, processing, Africa.

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1.0 Introduction

Cereals are important sources of the world's food supply and their role in human diet throughout the world is extremely vital. Cereal grains generally provide significant amount of nutrients and non-nutrients in the diet of populations all over the world, including developed and developing nations (Joshi *et al*., 2008). In the light of this, the major cereals contributing to diet in the world are rice, barley, maize, wheat, sorghum, oat, rye and millet (Mridula and Sharma, 2015).

From this lot, are millets, commonly referred to as small-seeded grains, belonging to the *Poaceae* (*Gramineae*) family (Zhu, 2014). They are regarded as minor cereals (Shobana *et al*., 2013) and are majorly known for their starchy edible seeds (Kothari *et al*., 2005). Millets are important source of nutrients and an indispensable food for millions of people in developing countries such as Africa (Filli *et al.*, 2010; Amadou *et al*., 2013; Mridula and Sharma, 2015). According to Joshi *et al*. (2008), millet is an important ecological food security crop known for its drought resistance and nutritional quality and can be an immediate subsistence food for a nutrient-scarce populace. This group of cereal crop has significant potential in widening the genetic diversity in the food basket and ensuring improved food and nutrition security (Mal *et al*., 2010).

For centuries ago and at present, millet have been processed to transform them into other food products to increase their palatability, aesthetic value, acceptability and sensory attributes. Fermentation and malting are few of the most used processing techniques utilized for the diversification and transformation of millet. According to Lei and Michaelsen (2006), these groups of foods continue to constitute 20-40% of the food supply worldwide. Particularly in

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ancient times and the situation in most developing countries where proper storage is unavailable, these processing techniques are widely utilized and of crucial importance. According to Onweluzo and Nwabugwu (2009) fermentation process prolongs the shelf-life of foods, increases protein content and digestibility, relative nutritive value, availability of minerals, functional properties and decreases the concentration of phytic acid while enhancing sensory properties and imparting antimicrobial properties on the food product (Jay *et al.*, 2005; Inyang and Zakari, 2008). Alternatively, malting is an easily adaptable technology which causes increased activities of hydrolytic enzymes leading to an increase in essential amino acids contents, total sugars, B-group vitamins, with a subsequent decrease in dry matter, starch and anti-nutrients (Traore *et al.*, 2004; Coulibaly *et al.*, 2012). Accordingly, both techniques maximize the levels of some of the utilizable nutrients and lower the dietary bulk in cereals (Akinhanmi *et al.*, 2008).

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Historically in Africa, millets are processed by using two basic food processing techniques; fermentation and malting to obtain different products. However with the trend and drive in industrialization and improvement of these processing techniques, millet has been transformed to give birth to new, contemporary value-added products, further creating a huge potential and opportunity for the evolution of other ones. This review thus presents an appraisal and expedition of fermented and malted millet products from a traditional and rural food product to the commercially available contemporary, modern and industrialized food product. This review also draws attention to its prospects which would further increase its utilization, diversification and consequent consumption.

2.0 Millets

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Millet is a generic term referring to an extraneous group of forage grasses (Table 1) recognized for producing small-sized grains (Muthamilarasan *et al.*, 2016). It is a word derived from the French word "*mille"* which means thousand, literarily indicating that a handful of millet has thousands of grains (Taylor and Emmambux, 2008). They belong to the grass family *Poaceae* (*Gramineae*) and are believed to be cultivated since establishment of human civilization (Shobana *et al.*, 2013). Species of this cereal crop have been said to originate from China, Asia and Africa (Oelke *et al.*, 1990). Relative to this, they are sometime referred to as the first cereal crop (Lu *et al.*, 2005). In terms of world production, it is the sixth most important cereal crop after wheat, maize, rice, barley and sorghum with an annual production of about 29 million tonnes in 2013 (FAOSTAT, 2015).

This crop is unique compared to other cereals like maize and rice, because of its superior nutritional qualities especially valuable amino acid, methionine, higher protein, quality macro and micronutrients (Shobana and Malleshi, 2007; Saleh *et al.*, 2013). Millets are also good sources of nutraceutical and functional food ingredients in health promotion, mainly due to their antioxidant, antimicrobial, anti-inflammatory, antiviral, anticancer, antiplatelet aggregation, and cataractogenesis inhibitory activities (Chandrasekara and Shahidi, 2011; Taylor and Duodu, 2015; Muthamilarasan *et al.*, 2016).

Though millets are usually consumed by people from the lower economic strata, they are nutritionally rich (Taylor *et al.*, 2010a; Saleh *et al.*, 2013). Millet has been termed as "nutri-cereals", because they are rich in vitamins and sulphur containing amino acids (Table 2) (Sangeetha and Devi, 2012). According to Leder (2004), millet contains 22-28% albumins and

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globulins, 28-32% glutelin and glutelin-like proteins, while its prolamin content ranges from 22-35%. These nutrients are reportedly lacking in diets of the poor who live mostly on starchy staple meals (Srivastava and Sharma, 2012). Millets are also rich sources of phytochemicals, polyphenols, soluble and insoluble dietary fibers, minerals, and antioxidants (Chethan and Malleshi 2007; Taylor and Duodu, 2015; Muthamilarasan *et al*., 2016). Its fatty acids are highly poly unsaturated and contain relatively high proportions of non-starchy polysaccharides (Hegde and Chandra 2005; Muthamilarasan *et al*., 2016). Millets are also known to slowly release sugars and consequently have a low glycemic index (Bala-Ravi, 2004). It is also gluten free, which makes it an excellent choice for people suffering from celiac diseases caused due to gluten intolerance (Taylor *et al*., 2006).

3.0 Processing of millet through fermentation and malting

Processing of foods is an essential step in transforming foods to improve sensorial, nutritive value and enhancing bioavailability of nutrients (Liu *et al*., 2012). Other desired physical and chemical changes include modification of the macro- and micro- structure of the product and starch digestibility (Concy, 2009; Amadou *et al.,* 2014; Dharmaraj *et al.,* 2014). Processing of millet has also been reported to decrease levels of antinutrients (Hotz and Gibson 2007; Taylor and Duodu, 2015). While several techniques have been utilized for processing millets, fermentation and malting are the oldest and most common forms of processing techniques (Pugalenthi and Vadivel, 2005; Singh *et al.*, 2015). This can be attributed to their relative simplicity, cheapness and availability. Notwithstanding, several attempts towards improved techniques for these processes have been made and are existing. These are highlighted in the proceeding sections of this review.

3.1 Fermentation

Fermentation is one of the oldest and widely used methods adopted for the processing of millets. It is a process dependent on the biological activity of certain microorganisms [lactic acid bacteria (LAB) and yeasts], leading to the production of a wide range of metabolites (Ross *et al*., 2002). It has been regarded as an economical technique of processing food and its relevance is evident in the myriad of available products in African.

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Simply defined, it is a process performed to transform substrates into new products through the action of microorganisms. Biochemical changes that occur during this process lead to the modification of the substrate and production of volatiles (Singh *et al.*, 2015). The fermentation process lead to the activation of enzymes, adjustment of pH and performance enhancement of certain enzymes including proteases, amylases and hemicellulases (Jay *et al.*, 2005). These changes result in the beneficial properties associated with fermentation including preservation through alcoholic, lactic acid, alkaline, acetic acid fermentation and the impartation of antimicrobial properties (Jay *et al.*, 2005). Fermentation also ensures the hygienic safety of the food by suppressing the growth and survival of undesirable microflora in food (Ross *et al*., 2002). According to Osman (2004) and Eltayeb *et al*. (2007), this process also leads to detoxification, decrease in trypsin and amylase inhibitory activity, phytic acid and tannins. Nutritional enrichment by increasing protein content, mineral extractability and palatability have also been reported (El Hag *et al*., 2002; Ali *et al*., 2003; Badau *et al*., 2005 Osman, 2011; Ranasalva and Visvanathan, 2014). Fermentation further results in a decrease in cooking time (Jay *et al*., 2005; Sasikumar, 2014) and enrichment of sensorial qualities through the development of diverse flavors, aromas and texture (Jay *et al.*, 2005; Kohajdova and Karovicova, 2007).

3.1.1 Natural or spontaneous fermentation

Majority of the fermented foods from Africa are being produced through natural or spontaneous fermentation. This process is mostly managed by women in households or at a commercial small scale level (Figure 1). Depending on the type of product, such fermentation could be only lactic acid fermentation or both lactic acid and alcoholic fermentation for the production of alcoholic beverages (Kohajdova and Karovicova, 2007). Under such conditions, millet grains are winnowed to remove debris, stones and other foreign materials. These are rarely cleaned and soaked into water for days (depending on the period required for the desired product). Spontaneously, fermentation results as a consequence of the competitive activities of different microorganisms and strains best adapted and with higher growth rates usually dominate (Aka *et al.*, 2014). Investigations into microbial populations responsible for this type of fermentation have been investigated over the years and a dominance of LAB have been reported (Galati *et al.*, 2014). Nevertheless, different undesirable species of bacteria, yeasts and fungi have been detected and implicated for contributing to spoilage and pathogenic traits (Humblot and Guyot, 2009; Aka *et al.*, 2014; Galati *et al.*, 2014).

Similar to natural or spontaneous fermentation is back-slopping, commonly practiced traditionally, in low-income households and small scale commercial enterprises. This involves the introduction of a small portion of a previous successful fermentation batch (Aka *et al.*, 2014)

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which serve as a source of starter cultures and guarantees the successful transfer of the responsible LAB responsible for fermentation.

3.1.2 Controlled fermentation

As earlier stated, undesirable microorganisms may develop during the spontaneous fermentation of foods and upon reaching a maximum level, undesirable microflora of fermentation could be detected in fermentation process (Corsetti and Settanni, 2007). Microorganisms implicated in such conditions include *Fusarium*, *Aspergillus*, *Acetinobacter*, *Candida*, *Enterobacter*, *Aerobacter* and *Bacillus* (Galati *et al.*, 2014). The presence and occurrence of these organisms represents a food safety concern as some are pathogenic while some of the fungal species produce some toxigenic mycotoxins (Abriouel *et al.*, 2006; Humblot and Guyot, 2009; Njobeh *et al.*, 2010; Oguntoyinbo *et al.*, 2011; Galati *et al.*, 2014; Adebo *et al*., 2015).

Over the years, several efforts have been directed towards the identification and selection of strains for a better fermentation process, referred to as controlled fermentation (Galati *et al.*, 2014). This had involved monitoring of dominant fermentation microorganisms and the analysis of the respective microbial biodiversity of fermented millet foods (Table 3). Controlled fermentation have since evolved into the selection of strains and starter cultures based on their specific biotechnological traits with a goal of obtaining final products of desired characteristics (Figure 1). While LAB is known for its rapid acidification, yeasts are selected for their higher alcoholic fermentation rate (Galati *et al.*, 2014; Singh *et al.*, 2015). Using the selected precise strain, the fermentation process is done under an optimal condition required by the strain, to yield a desired and safer product. Although concerted efforts from research entities, industries

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and the government have yielded commercially available strains, challenges including financial implications, social and religious beliefs of African inhabitants have frustrated a holistic acceptance of this approach.

3.2 Malting

Similar to fermentation, malting of millet is a traditional practice in Africa, where the malt is subsequently used in lactic acid and alcoholic fermented beverages and infant food production (Adekunle, 2012). It could be simply defined as the germination of grain in moist air under controlled conditions to promote the development of hydrolytic enzymes which were inactive in the raw grain (Taylor and Dewar, 2001; Ayernor and Ocloo, 2007). These hydrolytic enzymes structurally modify and solubilize the grain structure, causes the breakdown of carbohydrates, lipids and proteins to simple sugars, lipids and amino acids respectively (Adekunle, 2012; Patil, 2013; Swami *et al*., 2013). Malting also activates proteases which degrades protein and improves its bioavailability (Taylor *et al.*, 1985; Pyler and Thomas, 2000), decreases phytic acid and increases the extractability of calcium, iron and zinc in millets (Badau *et al.*, 2005; Lestienne *et al.*, 2005). This process has also been reported to enhance flavor and bioactivity of grains (Pyler and Thomas, 2000; Heinio *et al.*, 2001). In addition to starch degradation, there is a conversion of the proteinaceous matrix in the millet grain into polypeptides and amino acids by proteolytic enzymes (Umaru and Genwa, 2013).

The malting process involves three main operations, which are soaking, germination, and drying/kilning. The cleaned grains are stepped in water for 24 hours (Figure 2) after which they are drained. The wet grains are then spread on trays, floor or jute bags (Figure 2) for

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germination, and water has to be added intermittently to facilitate the germination process. During the germination process, the grains are raked and turned to keep grains loose and aerated (Taylor and Emmambux, 2008). The germinated grains are then dried under controlled temperature to obtain malted grains which can be further processed to other food products discussed in the later part of this review. Due to the warm and damp conditions of grains, during the malting process, growth of molds and fungi are encouraged. However in rare cases, some species of these fungi produce mycotoxins which have been implicated in different poisonous outbreaks (Njobeh *et al*., 2010).

Different researchers have suggested some propositions for a modern day malting process (Dewar *et al.*, 1997; Francakova *et al.*, 2012; Frere *et al*., 2013). These include steeping grains with caustic soda or chloride salt, keeping germination time possibly shorter, using turners to prevent clumping of the germinating grains and preventing germinative stress. Further innovative and controlled malting systems, to provide high quality malted products which will enhance utilization of millet have also been industrialized (Figure 3).

4.0 Traditional fermented and malted millet-based food products

Africa is home to a vast and large number of fermented and millet food products (Table 4), most of which are traditionally processed and delivered to its intended consumers. Notable examples of these traditional products are given below;

4.1 Gruels, porridges and dumplings

Ogi is a traditional gruel or porridge prepared from fermented millet, sorghum or maize (Blandino *et al.*, 2003). It is a staple food for the inhabitants of West Africa and a meal/weaning

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food for infants. *Ogi* (Figure 4) is traditionally prepared by soaking the grains in water for 24-72 hours, wet milling and sieving to remove the bran. The filtrate is further fermented for 2-3 days to yield *ogi*, a sour starchy sediment (Teniola and Odunfa, 2001). Traditionally, this product is often marketed as a wet cake wrapped in leaves or transparent plastic bags. Similarly to this is *ben saalga* (Figure 4), a semi-solid millet based gruel commonly eaten by children (Guyot *et al.*, 2003). It is a popular food in Burkina Faso (Tou *et al*., 2007) and its processing has been described to involve soaking, milling, sieving, settling (during which fermentation occurs) followed by a cooking process (Tou *et al*., 2006).

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Ghanaian *koko* is a millet porridge daily consumed as an in-between meal or snack (Muller, 1970; Lei and Jakobsen, 2004). Production is done by steeping pearl millet overnight, wet milling the grain (with spices), addition of water (to make slurry), sieving, fermentation and sedimentation (Lei and Jakobsen, 2004). This is followed by boiling of the top water and addition of the sedimented bottom layer to obtain the desired consistency (Muller, 1970; Lei and Jakobsen, 2004; Lei and Michaelsen, 2006). Likewise, *fura* (*furah*) (Figure 4) is a traditional semi-solid dumpling prepared by steam cooking of fermented moist flour balls of pearl millet, followed by pounding in a mortar and rolling (Owusu-Kwarteng *et al.*, 2010). It is a staple food in Nigeria, Ghana and Burkina Faso and produced by blending millet with water and spices, compressing them into dough ball and subsequent cooking (Jideani *et al.*, 2002). From Botswana and Southern Africa is *bogobe* (*ting*), made from fermented maize, sorghum or pearl millet. *Dégué* (*tchobal*) is also a spontaneous, fermented and gelatinized pearl millet product, consumed by children and adults from Burkina Faso (Abriouel *et al.*, 2006). After dehulling, the grains are grinded with water and steam cooked to produce gelatinized balls which are further fermented

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for 24 h and afterwards consumed with dairy products and juice (Abriouel *et al.*, 2006; Hama *et al.*, 2009). From Benin is *gowe*, a sweetish gelatinized, fermented and malted, cooked paste made from sorghum, millet and/or maize flour (Adinsi *et al.*, 2014). It is usually consumed as a porridge or as a beverage, after dilution with water and addition of sugar, ice and sometimes milk.

4.2 Alcoholic and non-alcoholic beverages

Alcoholic and non-alcoholic beverages produced from millet are more prevalent compared to other types of products. Pundits have argued that this can be attributed to survival instincts of the first African settlers. Known as *malwa, bantu, pombe*, opaque or *kaffir* beer are alcoholic beverages made from malted or fermented millet grains, although other grains such as maize and sorghum are commonly used (Figure 5). They are consumed in different parts of Central, East and West Africa and plays an important role in the culture and other social activities of the inhabitants of this region. *Bjalwa bja leotsa* and *ndlovo* are alcoholic traditional beers of the Pedi people and Zimbabweans respectively (Quin, 1959; Taylor and Emmambux, 2008). Similar to these other aforementioned alcoholic beverages, is *pito* (Figure 5) a light brown alcoholic beverage prepared from fermented millet or sorghum and consumed in Nigeria, Ghana and other parts of West Africa (Ajiboye *et al.*, 2014). It is a nutritious source of instant energy for Nigerian tribes and used for cultural purposes (Tamang, 2010). Accordingly, majority of these traditional millet beers are mostly consumed in their active state of fermentation. In Egypt *boza* (*buza, bouza*) is commonly brewed from pearl millet (Arici and Dagliogu, 2002). It is thick, pale yellow and has a characteristic acid-alcoholic aroma. Also in Ethiopia, a traditional beer and spirit has been prepared from finger millet is commonly known as *tella* and *katikalla* respectively (Bultosa and Taylor, 2004). In Benin and Burkina Faso, a similar traditional millet beer called *tchouk*, *dolo* or *chapalo* has also been prepared. *Merrisa* is a Sudanese traditional alcoholic beverage manufactured using malted sorghum or millet (Dirar, 1992; Lyumugabe *et al*., 2012). Its production has been described as a complex procedure and probably the most complicated brewing process of all traditional millet-based African alcoholic beverages (Lyumugabe *et al.*, 2012). The process has been extensively described and the resulting drink is reported to have a pH of 4 and alcohol level of 5% (v/v) (Dirar, 1976; Lyumugabe *et al*., 2012).

Kunu-zaki (*kunu*) (Figure 6) is a non-alcoholic fermented beverage commonly consumed in Nigeria, especially the Northern part (Blandino *et al.*, 2003). It is of high social and economic importance and can be prepared from maize, sorghum or pearl millet (Efiuvwevwere and Akona, 1995). Grains are washed, dried and coarsely ground. The resulting flour is mixed with hot water to form a paste which is spontaneously fermented for days to obtain the product. It is also spiced with ginger to improve sensorial qualities. *Oshikundu*, a similar fermented product has been prepared in Namibia from fermented-cooked pearl millet and sorghum malt flour (Taylor, 2004), while *togwa* is from maize meal and finger millet malt (Oi and Kitabake, 2003). In South-Western Uganda is *bushera* (*obushera*), a fermented and malted product of millet or sorghum, consumed by both young and old people in (Mukisa *et al.*, 2010). It is regarded as the most common traditional fermented beverage and a thirst quencher, energy drink and utilized for social purposes (Muyanga *et al.*, 2003). To prepare *bushera*, sorghum or millet malt flour is mixed with boiling water and left to cool, after which the malted millet/sorghum or a previously fermented batch is added to ferment for another 1-6 days (Muyanga *et al.*, 2003).

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Mageu (*mahewu*) (Figure 6) is one of the most popular cereal based beverage in Southern Africa and some other Arabian Gulf countries (Bvochora *et al.*, 1999; Mcmaster *et al.*, 2005). It is a refreshing drink and also a weaning beverage for infants. Although it is commonly prepared with maize flour, some ethnic groups use sorghum and millet instead. Its preparation starts with cooking maize meal in water until a thin porridge is obtained, cooling and addition of sorghum or millet malt after the cooking stage for fermentation (Simatende *et al.*, 2015). Another prominent non-alcoholic beverage in East Africa (notably Uganda) is *uji*. It can be made from sorghum, maize or finger millet and could be fermented and unfermented (Onyango *et al.*, 2004; Kohajdova, 2014). The fermented one is prepared by a spontaneous or back slop fermentation process after which it is boiled, sweetened and consumed hot (Nout, 2009; Kohajdova, 2010; Nyanzi and Jooste, 2012).

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4.3 Flatbreads and pancakes

Injera (Figure 7), is a leavened pancake with a honey-comb like texture (Belton and Taylor, 2004) and undergoes a mixed LAB and yeast fermentation (Gashe *et al.*, 1982). It is a common staple food in Ethiopia, Eritrea and Somalia. It is mostly made from *teff*, mixed with water and fermented for 24-48 hours. Part of the dough is gelatinized, remixed and baked. Gelatinization of the dough is to make the dough viscous and allow the *injera* rise and hold gas. Similar to *injera* is *kisra* (Figure 7), which is relatively thin, with neither holes nor a spongy texture (Badi *et al.*, 1989).

5.0 Value added and modern fermented and malted food products from millet

According to Jayne *et al.* (2014), five of the top ten fastest growing economies in the world are located in sub-Saharan Africa. This rapid economic transformation ongoing in the continent has spawned efforts channeled towards increasing industrialization and urbanization. This economic growth has thus led to the increased demand for convenience, RTU and RTE foods. By default, considerable and new opportunities towards the development of industries to meet this demand have risen.

Traditionally available raw materials and products are the first point of call to local and potential foreign investors and millet have positioned itself among other cereals as a viable resource. Additionally, demand for gluten free products from consumers with celiac disease has created a wider prospect for processed millet. As defined by Schuppan and Zimmer (2013), celiac disease is an inflammatory disease of the small intestine which arises in response to the consumption of gluten by genetically or medically intolerant persons. The primary and possibly best treatment of this allergy is through the consumption of a gluten-free diet (Rubi-Tapia *et al.*, 2013), which the consumption of millet based products readily provides. Hence, this section appraises and mentions some notable and significant fermented and malted millet based products which have transited from being a traditional home based product to a modern day commercially available merchandize, on the shelf in shops and stores.

One West African product that has undergone technological transformation over the years is *ogi* and *koko*. By the application of appropriate cereal science and technology, this produce have been transformed from the moist starchy sediment to a dehydrated packaged product (Figure 8). Further investigation into value-added potential of *ogi* have also led to the fortification of this

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product with vitamins and compositing with soy flour to produce soy-*ogi* (Figure 8). Responding to the needs of alcohol consuming celiacs, a brewing company, formulated and created a gluten free ale from millet and sorghum (Figure 8). *Mbege* ale is made from millet, sorghum and banana. Likewise is the success story of the Southern African opaque beer that has been industrialized, packaged and commercialized as *chibuku shake shake* (Figure 9). It remains a popular beer especially in Botswana, Zambia and Zimbabwe. In Nigeria is *kunun tsamiya*, an instant beverage modified from *kunun-zaki* and in Uganda is *bushera* (Figure 10).

Consequent to the birth of these commercialized fermented millet foods, many African countries where such products are manufactured have benefited from the industrialization of their indigenous fermented foods through value addition to millet and from sale of the final processed products. Further to this is self-empowerment and the daily profits which comes along with the sale of these products.

6.0 Future prospects

Millet stands as a cereal crop which has being potentially unexplored. They are however viable raw materials for the development of food manufacturing industries, in contrast to other cereal crops which are not locally grown in Africa. While malting and fermentation remains a cheap and economical way of transforming millets into value added products, the unavailability of RTE products have however hindered the acceptability and usage of these products. With a growing population coupled with the challenges of mal- and under-nutrition, food shortage and food insecurity especially in the developing world, millet is vital in addressing this. Although, numerous millet based products are available, there is a huge potential to develop diverse food

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products by using traditional and contemporary methods. Value addition to millets will thus offer variety, quality and convenience foods. With the growing demand for gluten free, functional and nutraceutical food products, millet products can be established as a substitute. Furthermore, these foods could be potential sources of beneficial bioactive compounds e.g. polyphenols which exerts health promoting properties and will address increased rates of diet related diseases.

7.0 Conclusion

While different studies have demonstrated the utilization of millet for food products, recommendations from such studies have been poorly accepted and rarely adopted by the appropriate authorities, thereby reducing wide range of acceptability. With the increasing need for the world to feed its growing population, it is imperative to explore food crops such as millets that are grown locally and consumed by low income households in developing nations. Moving forward, the agricultural productivity of this crop must be substantially improved to reduce their costs, which in turn make them more beneficial and attractive as compared to other cereals. Application of industrial processing technologies using modern equipment and optimized conditions will enhance the production of high quality and diversified food products at a commercial scale. This will further improve the productivity of millet and substantially contribute and drive economic development and food security in Africa.

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Table 1: Common millet species and botanical names

Species	**Common name**
Brachiaria ramose	Browntop millet
Coix lachryma jobi	Job's tears
Digitaria exilis	Hungry rice
Digitaria ibura	Fonio
Echinochloa colona	Jungle rice
Echinochloa decompositum	Australian millet
Echinochloa frumentacea	Japanese barnyard millet
Eleusine coracana	Finger millet
Eragrostis teff	Teff
Panicum miliaceum	Proso millet
Panicum miliare	Little millet
Paspalum notatum	Bahia grass
Paspalum scrobiculatum	Kodo millet
Pennisetum glaucum	Pearl millet
Setaria italic	Foxtail millet
Urochloa deflexa	Guinea millet

(Adapted from: Kothari *et al*., 2005)

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Table 2: Nutritional composition of millet varieties

	Finger millet	**Proso millet**	**Foxtail millet**	**Little millet**	***Kodo* millet**	**Barnyar millet**
Proximates						
Moisture (g)	13.1	11.9	11.2	11.5	12.8	11.9
Protein (g)	7.3	12.5	12.3	7.7	8.3	6.2
Fat (g)	1.3	1.1	4.3	4.7	1.4	2.2
Minerals	2.7	1.9	3.3	1.5	2.6	4.4
Dietary fiber (g)	11.5	-	2.4	2.53	2.47	1.98
Carbohydrates (g)	72.0	70.4	60.9	67	65.9	65.5
Energy (kcal)	328	341	331	341	309	307
Vitamins						
Carotene (μg)	42	0	32	0	0	0
Thiamine (mg)	0.42	0.20	0.59	0.30	0.33	0.33
Riboflavin (mg)	0.19	0.18	0.11	0.09	0.09	0.10
Niacin (mg)	1.1	2.3	3.2	3.2	2.0	4.2
Choline (mg)	-	748	-	-	-	-
Minerals and trace elements						
Calcium (mg)	344	14	31	17	27	20
Phosphorus (mg)	283	206	290	220	188	280

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	Finger millet	**Proso millet**	**Foxtail millet**	**Little millet**	***Kodo* millet**	**Barnyard millet**
Iron (mg)	3.9	0.8	2.8	9.3	0.5	5.0
Magnesium (mg)	137	153	81	133	147	82
Sodium (mg)	11	8.2	4.6	8.1	4.6	-
Potassium (mg)	408	113	250	129	144	-
Copper (mg)	0.47	1.60	1.40	1.00	1.60	0.60
Manganese (mg)	5.49	0.60	0.60	0.68	1.10	0.96
Molybdenum (mg)	0.102	-	0.70	0.016	-	-
Zinc (mg)	2.3	1.4	2.4	3.7	0.7	3.0
Chromium (mg)	0.028	0.020	0.030	0.180	0.020	0.090
Sulfur (mg)	160	157	171	149	136	-
Chlorine (mg)	44	19	37	13	11	-
Essential amino acids						
Arginine (mg/g N)	300	290	220	250	270	-
Histidine (mg/g N)	130	110	130	120	120	-
Lysine (mg/g N)	220	190	140	110	150	-
Tryptophan (mg/g N)	100	50	60	60	50	-
Phenyl alanine (mg/g N)	310	310	420	330	430	-
Tyrosine (mg/g N)	220	-	-	-	-	-
Methionine (mg/g N)	210	160	180	180	180	-

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	Finger millet	**Proso millet**	**Foxtail millet**	**Little millet**	***Kodo* millet**	**Barnyar millet**
Cystine (mg/g N)	140	-	100	90	110	-
Threonine (mg/g N)	240	150	190	190	200	-
Leucine (mg/g N)	690	760	1040	760	650	-
Isoleucine (mg/g N)	400	410	480	370	360	-
Valine (mg/g N)	480	410	430	350	410	-

(Adapted from Geervani and Eggum, 1989; Gopalan *et al*., 2009)

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Table 3: African based millet fermented foods and their respective microflora

Product	**Microflora**	**Product type**
Amgba	LAB, yeasts	Alcoholic beverage
Bel-saalga	LAB	Gruel
Bogbe	*Lactobacilli* and yeast	Porridge
Busa	*Lactobacilli*, *Saccharomyces*	Liquid drink
Bushera	LAB, yeasts	Non-alcoholic beverage
Dégué	*Lactobacilli*	Dumpling
Doro	LAB, *S. cerevisae*	Alcoholic beverage
Injera	*Candida guillermondii*	Pancake
Kenkey	*Lactobacilli* and yeast	Porridge
Kisra	*Lactobacilli*	Pancake
Kunu-zaki	LAB, yeasts	Gruel or beverage
Mahewu	*C. krusei, S. cerevisae, Lactobacilli*	Liquid drink
Merissa	*Saccharomyces*	Alcoholic drink
Ogi	Bacteria, yeasts	Gruel
Tchouhoutou	*Lactobacilli*, yeasts	Alcoholic beverage
Togwa	LAB, yeasts	Gruel or beverage
Uji	LAB	Porridge

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Table 4: Some fermented and malted millet products from Africa

Products	**Country**	**Reference**
Ben saalga	Burkina Faso	Franz *et al*. (2014)
Bushera	Uganda	Marsh *et al*. (2014)
Dégué	Burkina Faso	Franz *et al*. (2014)
Doro	Zimbabwe	Gadaga *et al*. (1999)
Dolo (*chapalo*)	Burkina Faso	Anon
Fura	Nigeria	Jideani *et al*. (2002)
Gowe	Benin	Adinsi *et al*. (2014)
Injera	Ethiopia, Eritrea	Gashe *et al*. (1982)
Kisra	Sudan	Gashe *et al*. (1982)
Koko	Nigeria, Ghana	Marsh *et al*. (2014)
Koozh	Nigeria	Ilango and Antony (2013)
Kunu-zaki	Nigeria	Obadina *et al*. (2008)
Mahewu	South Africa	Marsh *et al*. (2014)
Malt drink	Nigeria	Okonkwo and Ogbuneke (2011)
Masa (*waina*)	Nigeria, Chad, Burkina Faso	Egwim *et al*. (2013)
Masvusvu	Zimbabwe	Amadou *et al*. (2013)
Merissa	Sudan	Dirar (1992)
Ndlovo	Zimbabwe	Taylor and Emmanbux (2008)
Ogi	Nigeria	Teniola and Odunfa (2001)

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Ontaku (oshikundu)	Namibia	Uno (2005)
Tchouk	Benin	Anon
Ting	Botswana, South Africa	Quin (1959)
Togwa	Tanzania	Marsh *et al*. (2014)
Uji	East Africa	Onyango *et al.* (2004)

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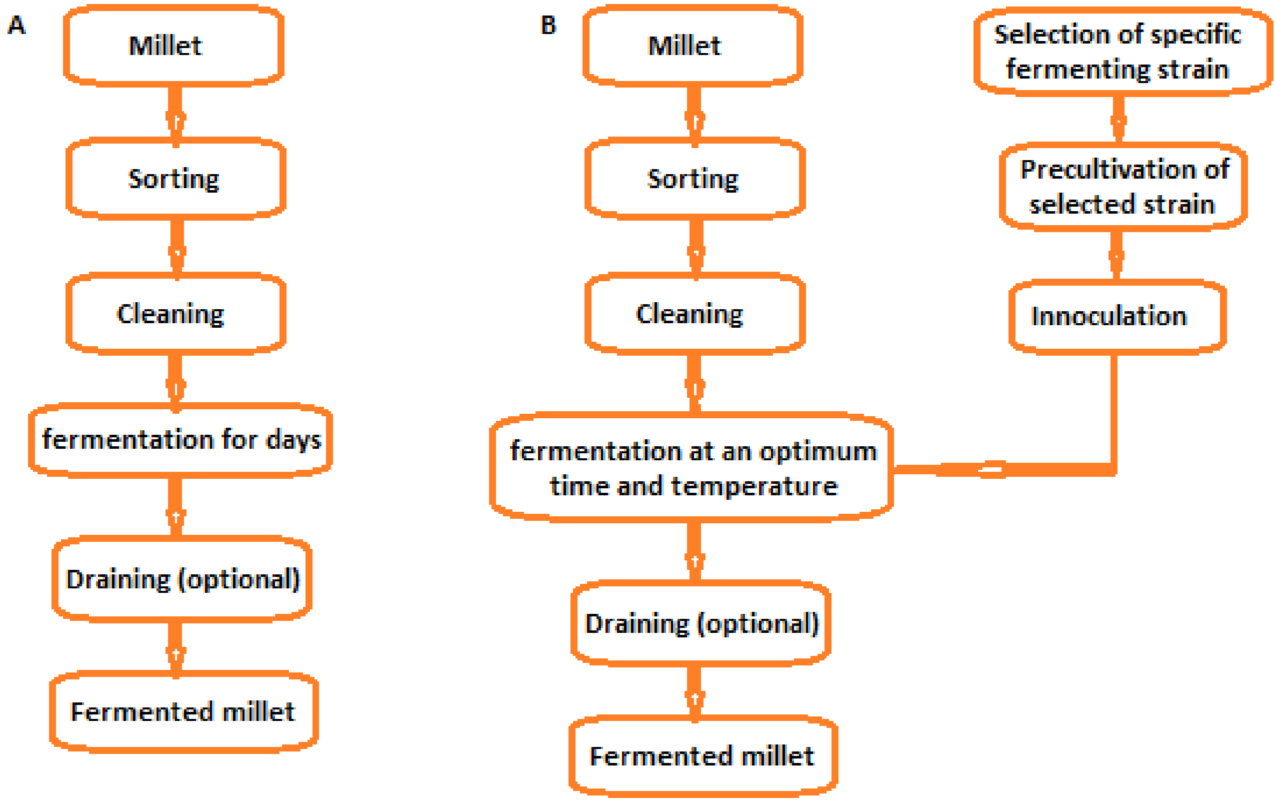

Figure 1: Natural/Spontaneous fermentation process for millet (A), Controlled fermentation process (B)

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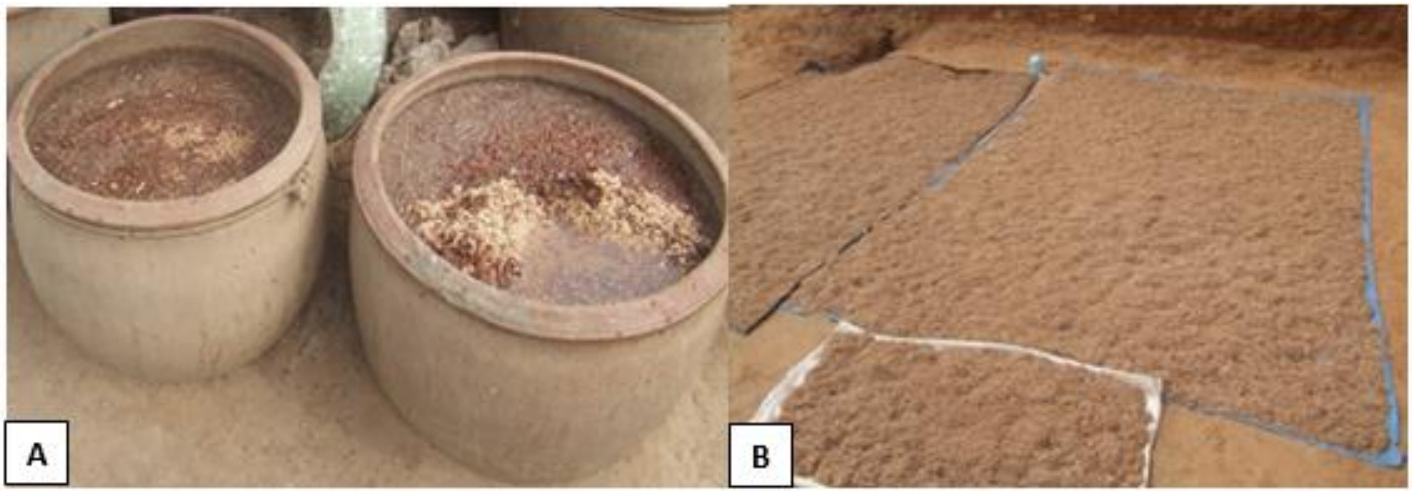

Figure 2: Traditional millet malting process; soaking (sprouting) in pots (A), germination on jute bags (B) (Adapted from Michael and Doria's Travel Tales, 2007).

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Figure 3: A modern industralized malting equipment (Adapted from Taylor, 2010b).

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Figure 4: Millet based gruel, dumplings and porridges; *Ogi* (A), *ben saalga* (B) (Adapted from Icard-Verniere *et al*., 2010), *fura* (C).

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Figure 5: Traditional millet based alcoholic beverages; *pombe* from Mozambique (A), opaque beer from Zimbabwe (B), millet beer from Cameroon (C), *pito* from Nigeria (D).

Figure 6: Traditional millet based beverages; *kunu* from Nigeria (A), *bushera* from Uganda (B), *mahewu* from Southern Africa (C) (Chipo, 2013).

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Figure 7: Millet based flatbreads/pancakes; *injera* being sold in an Ethiopian market (A), a Sudanese woman making *kisra* (B).

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Figure 8: Modern millet products; packaged *ogi* (A) and (B), packaged *koko* (C) and (D).

Figure 9: Modern millet based alcohol; gluten free ale (A), *mbege* (B), *chibuku shake shake* (C).

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Figure 10: Millet based beverages; instant *kunun* (A), *bushera* (B).

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