Chapter 18
African Fermented Vegetable Products

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18.1 Introduction

Vegetable products in the diet of people make significant contribution to enrich nutrition and health of the African Populations. Vitamins, minerals, antioxidants and dietary fibres are obtained from vegetable products. The consumption of vegetables can reduce the vulnerability to onset of chronic diseases. World Health Organization (WHO) and the European Food Safety Authority (EFSA) have shown that the intake of daily recommended vegetable has several positive health benefits (Giampieri et al. 2015). They help to prevent chronic diseases from the general gut health, boost immunity, skin health, cholesterol control and lactose intolerance. However, though majority of the vegetables are succulent making their consumption at fresh state palatable, they are prone to accelerated microbial spoilage. The fresh vegetables easily lose moisture and short shelf-life compromising their physiochemical qualities.

Various processing methods (cooking, drying, boiling, microwaving) have been reported for maintaining quality, reducing decay and extending shelf life of vegetables (Animashaun 2015; Guo et al. 2016, 2017; Talens et al. 2017). In addition, several types of preservatives that are used in modern processing of vegetables in order to maintain acceptable level of qualities between time of manufacturing and consumption. Key interest among the vegetable preservation methods is fermentation. Fermentation is an old food preservation technology with long traditional

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A. M. Elhadi Sulieman, A. A. Mariod (eds.), *African Fermented Food Products- New Trends*, https://doi.org/10.1007/978-3-030-82902-5_18

history in Africa, where activities of living organisms produce wide-range of metabolites with the capability to suppress the growth and survival of unwanted microflora in raw food materials (Ross et al. 2002). Fermented vegetable food products, globally are valued for their high sensory attributes in addition to what they have long been known for in food preservation and safety. For instance, as a food safety measure fermentation is been used as tool in the reduction of bacterial related food contamination; thus, this type of preservation that can help to reduce the incidence of diarrheal diseases (Zabat et al. 2018). Relatively, fermentation is relatively low-cost and most economical methods of food production and preservation over the years (Russo et al. 2017). In food processing, fermentation has been found to make beneficial contribution in the following ways: (1) Improve nutritive properties, diversity flavor (organoleptic properties) and convert inedible food to edible food (thus, make raw food digestible by possible removal of anti-nutrient factors, where necessary) (Smid and Hugenholtz 2010); (2) protect large quantities of food by lactic acid fermentation, (3) reduce toxicity or detoxify food ingredients and (4) shorten cooking time and reduce energy need.

Compared to the Asian and Mediterranean regions, the fermentation of vegetables in Africa is not well developed scientifically and for that matter no clear standards. The fermented vegetable products are anchored on the local raw vegetable varieties available within the specific to regions/ethnicity. Fermented vegetable products are consumed during the long dry periods when fresh vegetables may be in short supply.

This chapter describes fermented vegetable products in Africa, microorganisms in their fermentation and development of selected fermented vegetable-based products.

18.2 Microorganism for African Vegetable Products Fermentation

The process of fermentation actually involves diverse microorganisms and there is high diversity of the microbiome. Generally, most vegetable fermentation processes are based on the natural occurrence of lactic bacteria on external part of microflora. The presence of lactic acid bacteria (LAB) in several fermented vegetables are purposed to prevent the growth of spoilage bacteria through the production of bio-preservatives (Djien 1982). Lactic acid bacteria have a strong anti-bacterial effect as a result of the production of bacteriocins (Agriopoulou et al. 2020). The intake of lactic acid fermented vegetables supports the dietary enhancement of humans, promotion of growth of healthy intestinal flora and the positive health image of probiotics (Yamano et al. 2006). Fermented vegetables contain more vitamin C and the bioavailability of these vitamins also increases with fermentation (REF).

18.2.1 Dry-Salted Fermented Vegetables

Processing of vegetables by dry-salted fermentation is done by intentional addition of dry salt to vegetables. The purpose of the salt is to dehydrate the juice in the vegetables and make it saline. Here, for every vegetables of 100 kg, about 3 kg of salt is added. First the vegetables are cut, then wash in potable water and drained thoroughly. The sliced vegetables are arranged and put in a suitable container in a 2.5 cm layer for fermentation. Then sprinkle salt on the first layer of vegetables. Second layer of vegetables is added and salt is also sprinkled on them. This process is repeated to fill the container up to three quarters. In many instances, stones or heavy objects are placed on the layers to exert weight to compress the vegetables and to also promote the brine formation within 24 h. Shortly after the brine formation, fermentation commences and foams of carbon dioxide start to show. The ambient temperature largely determines fermentation period, which occurs between 7 and 30 days. When the appearance of bubbles completely stops indicates completion of fermentation process, before the pickle is packaged in a variety of blends (i.e., vinegar and spices or oil and spices) (Liu et al. 2011).

18.2.2 Brine-Salted Fermented Vegetables

In the brine-salted fermented vegetables (BSFVs), brine is applied to vegetables that characteristically have lower water content. The salt is dissolved in water to prepare the brine solution (Montet et al. 2014). According to Liu et al. (2011), the best fermentation occurs in brine with approximately 12.5 to 20° Salometer. When brine solution is strong, it induces solutions and carbohydrates out of the vegetables, and eventually decrease the internal salt concentration. It is critical to ensure that the concentration of salt should not drop under 10%; this condition will permit fermentation to occur (Panda et al. 2009).

Intermittently more salt is added to the brine mixture in order to prevent salt concentration from dropping. There is rapid microbial development in the brine as soon as the vegetables were put in the salt water and close the jar. Some of the natural parameters that affect the populations of microbes of the fermenting vegetables are salt concentration and brine temperature, the available fermentable materials and the numbers and kinds of microorganisms that exist at the time fermentation begins. According to Ray and Panda (2007), the speed of the fermentation correlates with the salt concentration in the brine and as well as its temperature. Most vegetables get fermented between 12.5 and 20° Salometer. When the salt concentration is very high (about 40° Salometer), the sequence is slanted to a homo-fermentation development, which is dominated by *Lactobacillus plantarum*. The highest concentrations of salt (60° Salometer), will stop lactic fermentation (Montet et al. 2006). However, they also indicated that any detection of acid (acetic acid) during brine storage is presumably produced by acid-forming yeasts; which are still active at the highest concentration of salt (60° Salometer) (Sruthi and Rao 2021).

18.2.3 Non-Salted Lactic Acid Fermented Vegetables

Without initial adding of salt or brine LAB can still ferment some vegetables (e.g., some wilted fermented leaves) (Tamang et al. 2005). Detoxifying cassava by fermentation comprise of an acid fermentation, where the cyanogenic glycosides are hydrolyzed to release the toxic cyanide gas (Onabolu et al. 2002). It is important to understand that the fermentation process is hitched on the ability of the LA-producing bacteria to rapidly colonize the food; this will lead to reduction in the pH and the environment become unsuitable for the growth of spoilage microbes. Also, the elimination of oxygen will enable the lactobacilli favour an anaerobic atmosphere. In other words, when oxygen is restricted yeasts do not grow (Montet et al. 2014).

In Table 18.1, various factors have shown to impact on lactic acid fermentation of Africa vegetable products. Definitely, these factors act in combination rather than independently to achieve the desire effect or the contrary.

18.3 Selected African Fermented Vegetable Products

The commonly consumed vegetables in Africa are listed in Table 18.2. These vegetables have very short shelf life and lose their eating quality quickly after harvesting unless they are processed into various products to add value. There are abundant levels of phytate and oxalate in the different vegetables and through fermentations these anti-nutrient substances are degraded (Wakhanu et al. 2014). The presence of these anti-nutrients (such as phytate and oxalate) limit the micronutrients release in the vegetables. The anti-nutrients bind to specific the minerals in the vegetables to reduce the micronutrient bioavailability. The product quality is positively affected by fermentation to retain minerals, β-carotene and α-tocopherol levels (Akello 2014). This section also discusses the fermentation activities in selected vegetables.

*18.3.1 Cowpea (*Vigna Unguiculata*) Leaves*

Cowpea leaves fermentation enhanced with the highest glucose concentration (3%) correlated with the highest concentration of lactic acid (0.6%) and the lowest pH of 4.7 (Kasangi et al. 2010). Also, blanched solar dried cowpea leaves and fresh solar dried cowpea leaves compared with fermented samples recorded the lowest crude protein (13.2%) and moisture content (6.2%) while that of crude fibre, ash and soluble carbohydrates of fermented samples increased. Fermented cowpea leaves also showed a reduction of iron, calcium, magnesium and zinc contents (Wafula et al. 2016).

Table 18.1 Factors that affect lactic acid fermentation of Africa vegetables

Factors	Observations	References
pH	Affects aroma and flavour. Almost neutral pH is benefit from most LAB. Certain bacteria (such as *Lactobacillus* and *Streptococcus*) are acid tolerant and able to survive low pH levels (3.0–4.0). pH	Kobawila et al. (2005), Muyanja et al. (2003) and Ray and Panda (2007)
Oxygen availability	Different species have different O_2 requirements. Most LAB are not sensitive to oxygen. They can grow in the presence and the absence of oxygen. They are known as aero-tolerant anaerobes.	Molenaar et al. (2005)
Temperature	Most LAB require optimum temperature between 20 °C to 30 °C. whiles some are thermophiles; thus, prefer high temperatures (50–55 °C), others tolerate colder temperatures between 15 and 20 °C. However, most LAB work best at temperatures between 18 and 22 °C.	Ray and Panda (2007)
Inoculum concentration	The concentration of HCL is between 20 and 80 g/l during fermentation. LAB can stand high concentrations of salt.	Rao et al. (2004) and Wouters et al. (2013)
Water activity	Mostly, LAB need a fairly high-water activity at 0.9 or higher, in order to survive. Few species can tolerate water activities lower than 0.9. Nevertheless, generally the yeasts and fungi will dominate on foods with a lesser water activity.	Ray and Panda (2007)
Nutrients	Source of nutrients is a requirement for all bacteria to undertake metabolism. Bacteria involve in fermentation require carbohydrates either simple or complex.	Ray and Panda (2007) and Wouters et al. (2013)
Selection of starter culture	The interactive effect between the starter and the natural flora in addition to the sensory properties of the final products are considered in selecting starter cultures for fermenting African vegetables. Also they are selected according to the absence of toxic chemicals production; capacity to produce only (L+) lactic acid; low or zero biogenic amines production; species must have attained their genetic stability; brine acidification must be rapid; ability to duplicate production among the different batch cultures, ability to totally deplete fermentable sugars	McFeeters (2004) and Montet et al. (2014)

*18.3.2 Baobab (*Adansonia digitata*) Leaves*

Baobab is seen as one traditional tree species of Africa's important leafy vegetables and issues related to strategies to manage leaf production have been seriously highlighted. For instance, the unique features of the palatable leaves, and the seasonal dimension of leaf consumption have been reported (Chadare 2010). Processing has effect on the quality of traditionally treated baobab leaves. A comparative study of *in vitro* digestibility and bioavailability of Ca, Fe, and Zn between non-processed

Table 18.2 Types of plant and their respective part fermented

Type of plant	Part fermented		
	Leaves	Fruits	Seeds
Amaranth (*Amaranthus spp*)	x		x
Okra (*Abelmoschus esculentus*)	x	x	
Cocoyam (*Xanthosoma sagittifolium)*	x		
Jute mallow (*Corchorus olitorius*)	x		
Kenaf (*Hibiscus cannabinus*)	x		
Cowpea (*Vigna unguiculata*)	x		
Sweet potato (*Ipomoea batatas*)	x		
Luffa (*Luffa spp*)		x	
Bitter leaf (*Vernonia amygdalina*)	x		
African eggplant (*Solanum melongena*)	x	x	
Water leaf (*Talinum fruticosum*)	x		
African spider plant (*Cleome gynandra*)	x		
West Indian nettle			
Pumpkin (*Cucurbita maxima*)	x	x	
Moringa (*Moringa oleifera*)	x		
Baobab (*Adansonia digitata)*	x		
Cassava *(Manihot esculenta)*	x		
Tomato *(Lycopersicum esculentum L.)*		x	
Onions (*Allium cepa*)	x		
Castor seed (*Ricinus communis*)			x
Cucumber (*Cucumis sativus*)		x	
Roselle (*Hibiscus sabdariffa*)	x	x	x
Turkey berry (*Solanum torvum*)		x	
Black plum (*Vitex doniana*)	x		
Eggplant (*Solanum macrocarpon*)	x		

and processed baobab leaves revealed the availability of total Ca (10–30%) and further stated that lutein and beta-carotene constitute the most vital carotenoids. Although, the *sweet leaves* type is preferred to the *bitter leaves*, the *bitter leaves* contain more nutrients.

The fermented baobab products have been categorized as thus, *Tayohounta* produced from fermented kernels; *Dikouanyouri* produced the fermented seeds, both are used as flavouring agents; *Mutchayan* (sorghum paste with baobab pulp) used as a drink and a main dish; and *Kuka* (processed dry leaves). Fermentation of the kernels and seeds is started mainly by *Bacillus* spp. (8.5 and 9.5 Log cfu/g, respectively) and that of the sorghum paste with baobab pulp mostly fermented by lactic acid bacteria (8.1 Log cfu/g) and yeasts (7.2 Log cfu/g) (Chadare 2010). same studies on the microbes on kernels indicated that the microbiota in-charge of the fermentation were spore forming bacteria, primarily *Bacillus subtilis* and other *Bacillus* spp.

18.3.3 *Cassava (*Manihot esculenta*) Leaves*

Cassava leaves are popular indigenous leafy vegetables in diets among African people. Cassava leaves are high in proteins, minerals and vitamins. It was detected that proteins in the cassava leaves are rich in essential amino acids apart from methionine and phenylalanine (Gómez and Valdivieso 1985; Ravindran and Ravindran 1988). Cassava leaves and roots are also rich in cyanide (Liener 2012). Actually, classification of cassava is based on the cyanhydric acid contents. According to earlier reports by Mlingi et al. (Mlingi et al. 1991), cyanogenic glucosides is the main reason for the toxicity of unfermented cassava leaves. When linamarine is not hydrolyzed, the residuals in the cassava leaves after fermentation process constitute a health risk for the consumers (Gómez and Valdivieso 1985). It was confirmed that the continuous ingestion of cyanide contaminated fresh or minimally processed food poses a high risk to consumer. Intake of non-detoxified cassava products has been found to contribute to certain diseases indirectly caused by the cyanide. These diseases include goitre, dwarfism and the tropical ataxic neuropathy. Especially, in regions where cassava is the main source of energy, these diseases are serious issues of worry (Balagopalan 2002). Breeding programs have been carried out to produce cyanide-free cassava varieties or acceptable cyanide contents. Other traditional methods have been developed in various countries in Africa to remove the cyanhydric acid in the cassava leaves to make is safe for consumption. Traditional method of fermenting cassava leaves, significantly reduced the cyanogenic glucosides content between 70 and 75% (Kobawila et al. 2003). In fermentation of cassava leaves, the cyanogenic glucosides hydrolysis occur in alkaline (pH 8.5) environment (Kobawila et al. 2005).

The occurrence of cassava leaves fermentation in alkaline pH could be attributed to amines produced by *Bacillus* (Louembe et al. 2003). Certain Bacillus strains especially *Bacillus pumilus*, have the ability to use cyanhydric acid for their nourishment (Knowles 1976). Therefore, the Bacillus strains can cause the reduction of the cyanide content in the fermentation medium. Furthermore, the alkaline pH facilitates cyanogenic glucosides content reduction since cyanohydrin acetone production by the hydrolysis of linamarin, cleaves naturally once pH is more than 5.0 or by the action of hydroxynitril lyase to give acetone and cyanhydric acid.

In the Congo (in the Central Africa) a type of vegetable gotten through a semi-solid fermentation process of cassava leaves is called "*ntoba mbodi*" (Kobawila et al. 2005). The type of cassava leaves, conditions of fermentation and the microbes participating in the fermentation have significant effect on the sensory qualities (colour, texture, smell, taste) of the final products.

18.3.4 Cucumbers

Africa also produce pickled cucumbers. Cucumbers an important fruit vegetable and it is processed by lactic acid fermentation; afterwards the product color changes from pale to darker green and more transparent product. Fully mature cucumbers with no physical damaged are cleaned in potable cold water and drained. Then salt (1 kg) is added to the cucumbers. Insertion of the cucumbers in salt brine of 5% is a satisfactory technique. Here, the cucumber has a habit of absorbing salt until there is equilibrium between the salt in the cucumbers and the brine (approximately 3% salt in the brine) (Reina et al. 2005).

Fermentation commences and foams of carbon dioxide appear immediately the brine is formed. Fermentation period is 7 to 16 days depending on the ambient temperature. When the salt concentration is appropriate it places a selective effect on natural flora; this will lead to growth of LAB. As soon as the pH is near 4.7, the brine is inoculated with either *Lb. plantarum* or *P. pentosaceus* or their combination (Steinkraus 2002). Salt is usually added to the LA fermented cucumbers when the fermentation ends. The addition of salt will halt any unwanted bacterial growth during storage (Kapur and Singh 2003). Often, cucumber pickle is kept in clean jars with an overlaid. The quality of final products is maintained when they are stored in a cool place. The risk of food poisoning is also low because of the high acid level (3.1–3.5) of the ultimate product (Tamang et al. 2005).

18.3.5 *Onions (*Allium cepa*)*

Different varieties of onions (*Allium cepa*) such as sweet, white and yellow storage were used for LA fermentation. White and yellow bulb onions are generally processed type due to their high solid content, so they are selected for fermentation. Sweet onions are a spring/summer types with low solids and mild flavour and are often used at the fresh state (Swain et al. 2014). Lactic acid fermentation is used to process different bulb onions to sour onion.

A reported on the fermentation process indicated that first the onions were sliced and salt without or with sugar were added. Temperature condition during fermentation was 18 °C. In the case, where the onions did not have the required LAB for anaerobic fermentation, the sample as inoculated with brine obtained from sauerkraut or slices of cabbage. The final product after fermentation is sour onion with pH of 3.25–3.35 and 1.2–1.5 g LA/100 ml, (all within the range as the sauerkraut). According to the sensory assessment results, the yellow bulb sour onion was the preferred product in terms of color, texture and flavor. Also, the sour onion possessed a tartaric acidic taste, same as sauerkraut, the flavor was onion-like but without the pungency of fresh onions (Roberts and Kidd 2005).

18.3.6 *Castor Seed* (Ricinus communis)

Ogiri-igbo is a local name in Nigeria for final product of castor oil seeds fermentation, used as a condiment. According to Egwim Evans et al. (Egwim Evans et al. 2013), the microorganisms in the fermentation of castor oil include *Lactobacillus sp. Rhizopus stolonifera, Streptococcus sp., Aspergillus fumigatus, Pediococcus sp. Triscelophorus monosporus, Bacillus sp., Coryneform bacteria*. The raw castor oil seeds are cooked for 2 h until the seed turn to brown colour. After that the seeds are dehulled and rinsed in clean water. The boiled seeds are cooked for another 1 h. Then cooked seeds are cooled and enveloped in adequate banana leaves, and subsequently packed in a hygienic container with cover to ferment at room temperature (Egwim Evans et al. 2013).

18.3.7 *Amaranths* (Amaranthus *spp.*)

The shelf life for Amaranths after harvest is 3 days at ambient conditions (Peter et al. 2014). Therefore, fermentation among other techniques can be used to process the harvest to reduce postharvest losses and make products availability all-year-round. For more than two decades now, there have been research alternatives to produce bread that is gluten-free to satisfy celiac consumers. Amaranth seeds are among the several alternatives to the commonly gluten-containing grains. Amaranth seeds are considered one of the pseudo-cereals (Alvarez-Jubete et al. 2010; Poutanen et al. 2009) and nutrient-dense whole grains incorporated in gluten-free bread preparations with the potential to increase the dietary value of bread and bread products, in respect of fibre, protein and mineral contents (Moroni et al. 2009). Recently, some researchers (Kiskini et al. 2007; Kiskini et al. 2012) produced iron-fortified amaranth-based bread which met the sensory qualities consumers preferences. The fermentation of amaranth as substrate in bread can also bring a new trend in the development of new functional foods suitable for celiac patients or for people suffering from lactose intolerance.

18.4 Conclusion

African countries require food processing methods that are suitable, conducive for the tropics and relatively inexpensive to rural and urban populations. One of such methods is fermentation; the process has been developed based on indigenous knowledge for a wide variety of food products. Among these food products are vegetables. Fermentation is a component of food processing which contributes to the improvement of food safety, nutritional values, flavour and acceptability. It also helps to reduce anti-nutrients, detoxify poisonous compounds, prolong shelf-life and enhance the functional properties. Juices in vegetables are appropriate substrates for lactic acid fermentation or as conduit for probiotic bacteria. Various factors have been observed to affect lactic acid fermentation. Besides, lactic acid fermentations occur under three basic types of conditions (dry-salted, brined-salted and non-salted). In particular, addition of salt in vegetable fermentation is an important stage helps the growth of LAB.

Generally, African fermented vegetables are connected to many sociocultural characteristics of different people in the region. Lastly, understanding of the association between raw vegetable materials, beneficial microorganisms, and their environment is important to improve fermentation process and, quality and safety final products.

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