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The Role of Plantain in Promoting Food Security: A Review

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Abstract

Plantain is a food security crop of significant nutritional value in the global south. Yet there are significant post-harvest losses, especially at the senescent stage. This review seeks to give a general overview of the crop, its nutritional significance and the technologies that can be adopted to enhance its utilisation at its senescent stage. In West Africa, plantains are eaten at all ripening stages, yet processing is limited to the unripe and semi-ripe. Adoptable technologies such as foam-mat drying will enhance its utilisation in indigenous meals and other food applications. This review provides useful insight to optimize the use of plantain to prevent food waste.

Keywords

Food Security, Plantain, Foam-Mat Drying, Ripening

1. Introduction

It is estimated that approximately 2.5 billion tonnes of all food produced globally goes to waste. This includes waste from the farm, processing, shops, restaurants and homes. These wastes have been attributed to poor storage and transportation systems, especially in the global south, confusion over date markings, processing waste, consumer quest of buying aesthetically appealing produce and spoilage-associated factors including over-ripening of fruits, among other reasons [1] [2]. This current phenomenon is a threat to the realisation of Sustainable Development Goals 2, 12 and 13 (SDGs 2, 12 and 13), thus ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture, responsible consumption, and production and climate action respectively [3]. To achieve these SDGs, there needs to be a deliberate plan for responsible utilisation and consumption of commodities through the reduction of food waste at retail and consumer levels and also minimising production losses and food losses in the supply chain. This will make more food available to feed people. Reducing food waste plays a pivotal role in attaining environmental sustainability as it is estimated to contribute to about 10% of the total global greenhouse gas emissions [4]. Cities in the global south are facing a deepening food insecurity crisis, which is manifested in food poverty, hunger and malnutrition [5]. Yet the utilisation of agricultural produce is yet to be optimised. One commodity with great potential to improve food security in the global south is Plantain (*Musa paradisiaca*).

Musa paradisiaca (plantain) and *Musa sapientum* (true banana) are both triploid (2n = 3x = 33, where x = 11) belonging to the AAB group [6] [7]. Depending on the contribution of *Musa acuminata* and *Musa balbisiana,* there are other banana plant cultivars that have been classified into genomic groups such as diploids (AA, BB, AB), tetraploids (AAAA, ABBB) and other triploids in addition to plantain (AAA, BBB, ABB) [8] [9] [10]. The Food and Agriculture Organisation (FAO) and the International Institute of Tropical Agriculture (IITA) recognise the sweeter *Musa* species that are eaten uncooked as "banana" and "plantain", which are *Musa* species that have relatively higher starch content and require cooking before eating. However, many researchers use "banana" to mean all *Musa* varieties, which includes plantain [11]. In this review, the FAO and IITA definitions of plantain are used.

Plantain is the most popular and preferred among the cooking bananas in West Africa and constitutes nearly a third of the global production of bananas [12]. Plantains and other cooking bananas have great similarities with the appearance of unripe dessert bananas (*M. cavendish* AAA). However, plantains and cooking bananas are normally bigger. Plantains are seedless, consisting of pulp and peel. Cell division of the internal part of the pericarp forms the pulp [13]. The growth of the peel reduces drastically upon maturity, even though some fruits experience splitting, which is a disincentive for commercial fruit. Plantains can be classified as white or yellow cultivars based on their pulp colour. The yellow cultivar has a higher starch yield compared to the white. However, the granule structure in the yellow cultivar is weaker than its white counterparts [14]. Both the white and yellow pulp varieties have similar peel colours at maturity and ripening.

Plantain is utilised at all stages of ripening [15]. However, waste due to overripening is high as industrial application and utilization are limited, and most of the fruit is consumed in its unprocessed form [16]. The overripe plantains are not being exploited. A comprehensive insight into existing technologies for enhancing the storage life of overripe plantain pulp and their utilisation will reduce its losses. This review is aimed at giving an overview of the production, maturity indices, ripening, nutritional composition and post-harvest utilisation of plantain. The potential uses of overripe plantain pulp and adaptable technologies for processing to improve its utilisation and ensure food security and economic sustainability are also discussed.

2. Plantain Production, Distribution and Marketing

Plantains and bananas are together the fourth largest global food crop after rice, wheat and corn [17] and the most abundant fruits produced globally (in terms of quantities) [18]. In Sub-Saharan Africa, where plantain production is about a third of the total 100 million metric tonnes produced annually worldwide, it is a vital staple crop used in managing food security [19]. Ghana, Nigeria, Cote d'Ivoire and Guinea are the top producers of plantain in West Africa [20]. Small-scale farmers cultivate plantains produced in Ghana, and over 90% are either for sale locally or for domestic use [21] [22]. However, Ghana's impact as one of the top plantain producers is not felt on the global export market. The top three plantain exporting countries in the world are Ecuador (12.6%), the Philippines (9.6%), and Guatemala (8.1%).

With a steady increase in the production of the crop, plantain makes a remarkable contribution (13.1%) to the Agricultural Gross Domestic Product (AGDP) of Ghana and is ranked third after yam and cassava [12] [23]. It is a key source of livelihood for rural dwellers, and its importance as a cash crop is increasing with increasing urbanisation and utilisation, impacting the Gross National Product (GNP) [22] [24] [25].

3. Harvesting Maturity Indices and Physiological Changes during Ripening

Plantains are harvested unripe since they ripen and deteriorate quickly [9]. They are harvested between 75% and 90% maturity, depending on the target market [26]. Produce meant for export or sold far away is harvested between 75% and 80% maturity, while those meant for the local market are harvested at about 90% maturity. The harvesting maturity of plantains has been linked to the rate of deterioration due to ripening [16]. Indicators of plantain maturity that inform harvesting are the fruit weight, pulp-to-pearl ratio, changes in peel colour, floral end brittleness and disappearance of finger angularity [21] [27]. Other objective methods include the diameter of the fruit, bunch age and length [24] [28]. As plantains mature, pulp accumulation increases, which increases the finger diameter.

The peel colour is the most frequently used method of assessing fruit maturity. The change in peel colour from green to yellow is often an indication of maturity during ripening [29]. In the ideal situation, plantain fruit should be harvested when the peel is green in colour to withstand the rigours of handling and distribution [28]. That notwithstanding, external factors such as strong winds and rainfall influence the harvesting periods of the crop, where farmers are forced to harvest even below 75% maturity. This results in fluctuations in the price of the commodity according to demand and supply [21] [24] [30]. It is therefore noteworthy that the plantains being sold on the market are of variable maturity. The maturity of the plantain upon harvest is not only important in influencing its rate of ripening but could also influence the biochemical composition and eating quality of the ripe fruit [24].

Ripening of plantain

Ripening is a biochemical process in fruits initiated by the presence of ethylene that involves a series of physiological changes in texture, colour, flavour and aroma. Plantain is a climacteric fruit, thus, by implication, undergoes ripening. The ripening process of all climacteric fruits is grouped into three phases: the pre-climacteric phase, the climacteric phase and the post-climacteric phase (senescence).

At the pre-climacteric phase, the fruit remains unripe (thus green in colour), ethylene production is virtually negligible, and the basal respiration rate is low. The green life of the plantain has been reported to depend on the harvest maturity and the variety [31]. However, the storage temperature, relative humidity and composition of gases in the storage environment influence the duration of the pre-climacteric phase [30] [31] [32] [33]. While there is a chilling injury when the fruit is stored at a low temperature (≤11.5˚C), the pre-climacteric stage is shortened rapidly at temperatures above 25˚C. The pre-climateric duration can be enhanced by storing the fruit in an environment with high Relative Humidity (RH). The higher the RH, the lower the moisture loss, hence delayed ripening.

Modified atmosphere packaging of the fruits to obtain low oxygen concentrations (4%) and high carbon dioxide concentrations (7%) also affects the green life of plantains. Exposure of fruits to high carbon dioxide concentrations inhibits ethylene synthesis, which will initiate and sustain ripening. Exposure of bananas to modified atmosphere packaging at a temperature as low as 10˚C has been reported to slow down chilling injuries in bananas drastically [32]. According to Choehom *et al.* [34], modified atmosphere packaging inhibits senescent spotting in bananas. The process involved packing banana fruits with polyvinyl chloride films and keeping them in environments with low oxygen levels and high relative humidity. Kerbel [13] has also reported modified atmosphere packaging of bananas and plantains using polythene bags. Optimum oxygen and carbon dioxide concentrations between 2% and 5% are ideal to delay ripening and extend the shelf-life of plantains and bananas up to three times their normal duration [35] [36]. Plantain and banana fruit storage outside the optimal oxygen and carbon dioxide concentration may cause fruit discoloration, improper flavour development and undesirable texture [37] [38].

Alternatively, the application of coatings in the form of waxes increases the per-climacteric phase of fruits and vegetables, thereby delaying ripening. The coatings seal the stomata cell and cause a slowdown of moisture loss, thus reducing respiratory activities, which lead to ripening. Various edible coatings have been employed to prolong the ripening process of fruits and vegetables. These coatings include chitosan [39] [40], polysaccharid-based composite coating [41], and chitosan-glycerol coating [42]. Other edible coatings such as gibberellic acid, calcium chloride, 1-methlcyclopropene, and jojoba wax have been investigated to extend the shelf-life of banana fruit [43]. Similarly, Sugri *et al.* [44] reported that applying a thin layer of shea butter (about 0.05 mm coating) to *apem*, a*pentu*, o*niaba* and *asamienu* increased their per-climacteric lives by 22, 20, 17, and 15 days, respectively. Plantain farmers might take advantage of this simple technology, especially in Ghana, where shea butter is plentiful.

The commencement of the respiratory climacteric phase is spontaneous. There is a fast and well-defined rise in respiratory rate, which is associated with the evolution of ethylene. This is subsequently followed by the breakdown of chlorophyll in the peel, leading to changes in the pigment of the peel. There is also the conversion of starch to sugar and the softening of the pulp and peel [29] [45].

During the maturation of the plantain fruit, there is a progressive accumulation of starch, especially in the pulp, until harvest. As ripening commences, the starch, being the major carbohydrate source in the fruit, is converted into sugars, thus sucrose at the early stages and then glucose and fructose at the latter stages of ripening. The enzyme sucrose phosphate synthetase is responsible for the conversion of the stored starch into sucrose. After that, acid hydrolysis converts sucrose into glucose and fructose [46] [47]. Even though there is a complete breakdown of starch into sugars in the dessert banana when it is overripe, there remains some amount of starch (about 3%) in plantains at that same stage [48]. The accumulation of sugars during ripening results in an increase in the total soluble solids, thus increasing the sweetness of the pulp. This has been associated with the fruit as ripening progresses [31] [49] [50] [51].

Several authors [29] [33] [52] [53] have reported textural changes in plantains and bananas during ripening. The softening of the plantain tissues during ripening has been attributed to three main physiological processes that occur. They include the increase in pulp-to-peal ratio, the breakdown of starch into sugars, the breakdown of the cell wall, and the movement of water from the fruit peels to the pulp [48]. These phenomena decrease the hardness in terms of the puncture force of the plantain and reduce the turgidity of the peels, easing peeling. Prabha and Bhagyalakshmi [49] have elaborated on other carbohydrase activities (such as pectinase, cellulase, hemicellulase, amylase, laminarinase and xylase) that hydrolyze and convert carbohydrate compounds in banana fruit, which even affect the texture. Their microscopic studies confirmed the loss of the cell wall structural integrity, which led to the softening of the banana tissues.

The main pigments in plantains and bananas are chlorophyll and carotenoids. The carotenoids are unmasked during ripening, giving rise to the yellow coloration. Plantain goes through 10 different colour changes during ripening [27] [54] [55]. There is a specific peel colour that characterises every ripening stage. It starts from Stage 1, where the crop is all green (unripe), through Stages 3 to 5 (semi-ripe to ripe), where there are varying mixtures of green and yellow colours. At Stage 6, the plantain is yellow but has some green coloration at the tips, which disappears at Stage 7, where the plantain becomes fully yellow. By Stage 8, the fruit starts developing black spots, also known as senescence spots, which gain dominance by Stage 10 ripening. The colour changes are temperature-controlled. However, the above is generally observed when the fruit is stored at room temperature (23 to 26 ˚C) for post-harvest maturation.

The post-climacteric phase, or senescent phase, of ripe plantains begins at Stage 7. At this stage, there is rapid deterioration and proliferation of various microbes on the peels. However, metabolic activities are slowed down [47]. Other changes that occur during ripening include changes in the phenolic compounds, mainly the tannins responsible for the astringency of plantains when unripe. There is also the production of flavour and aroma compounds in the form of amyl esters and butyl esters responsible for the banana flavour and fruit flavour [56].

As ripening may be controlled to increase the shelf-life of plantains and banana fruits, in the same vein, ripening agents may also be employed to facilitate plantain ripening. Several ripening agents, such as ethylene glycol, ethylene gas, ethephon, and etherel, have been used [57]. Others, including African bush mango fruit (*Irvingia gabonesis*) and leaves, yellow pawpaw leaves, cassia leaves, palm nut, and potash, have been used locally [58]. Adewole and Duruji [59] have also reported the use of *Newbouldia laevis* leaves as a ripening agent. These ripening agents can hasten the ripening of the plantain fruit between 1 and 7 days.

In commercial banana and plantain production, ethylene is used in a controlled atmosphere (controlled temperature and Relative Humidity (RH) conditions) to ripen the fruits for sale. The fruits require a very low ethylene concentration for ripening (10 to 50 $\mu L \cdot L^{-1}$). However, for uniformity in ripening and the fact that most of the ripening chambers are not airtight, an ethylene concentration of about 1000$\mu L \cdot L^{-1}$ is used to make up for associated leakage and maintain enough ethylene for ripening [30]. This technology is, however, quite expensive for the indigenous seller. Therefore, they resort to local ripening agents, some of which are harmful to their health. Studies have shown that some of these harmful ripening agents, such as carbide, increase the amount of lead (Pb) in the fruit [60]. Plantain traders who want to sell their produce ripe usually induce the ripening process by stocking in wooden boxes, baskets, drums, polyethene bags, jute bags and sacks, tarpaulin and clothes in a natural cool-dry environment or by ripening agents. These containers are aerated by removing the covers after 2 to 4 days [58].

The rate of ripening is also affected by temperature, humidity and the rate of ventilation [47]. These factors also influence the texture and other sensory qualities of the ripe fruit [13] [36]. Commercial ripening of plantains and bananas is done at a temperature range of 14˚C and 20˚C, with the latter being the optimum but not exceeding 25˚C. Relative humidity ranging from 90 - 95% is also required, but the levels are reduced to 85% after the unset of the yellow coloration of the fruit to avoid peel splitting [30]. Ripening of plantains and bananas above or below the required temperature results in inferior quality fruits. At high temperatures, there is poor coloration, softening and decay, weakening of the fruit neck, and peel splitting. Fruits that are left to ripen on the plant often split and have inferior texture [13].

Managing plantain fruit ripening is essential for extended shelflife and improved sensory qualities at all stages of ripening.

4. Nutritional and Physicochemical Changes in Plantain during Ripening

Plantains have an appreciable nutrient density. They are rich sources of carbohydrates, minerals and vitamins and have considerable amounts of phytochemicals such as unsaturated fatty acids and sterols. Nevertheless, they are low in fat [56] [61].

Plantains contribute significantly to the energy content of the diet of consumers [11]. The total energy value of plantains (128 Kcal/100g) is higher than that for sweet potato and Irish potato of equal weight but lower than cassava, maize meal, milled rice and wheat flour [11]. Generally, the starch content of plantains is high, decreasing as ripening progresses [27] [47]. Unripe plantains contain more than 80% starch (DMB) and only 1.3% sugar. The sugar content significantly increases to about 17% in ripe plantains. Unripe bananas, however, have about 20% starch, which declines to 1 - 2% in the ripe fruit, while the sugar content increases from less than 1 - 20% [62]. At the early ripening stages, sucrose is the predominant sugar, but it is later dominated by glucose and fructose at later stages of ripening [47]. Other sugars present in minute quantities are maltose and rhamnose [8].

Ketiku [63] reported higher levels of protein in unripe plantain peels (8% DMB) than the pulp (3% DMB). He also observed a slight increase in the protein contents of both the peel and the pulp of the plantain upon ripening. Izonfuo and Omuaru [64] supported these findings. In their evaluation of the chemical composition of plantain peels and pulp at five different ripening stages, they also obtained far higher peel protein values than the pulp protein. There was also an increasing trend in protein values as ripening proceeded. Similar patterns in the increase in pulp protein during ripening have been reported in Cavendish banana pulp (John & Marchal, 1995 [47]). Enzymes such as chitinase are the most abundant proteins in unripe banana fruits. As the fruit ripens, enzymes such as isoflavone reductase, pectate lyase, maltate dehydrogenase, starch phosphorylase, S-adenosyl-L-homocysteine hydrolase, and amino cyclocarboxylic acid oxidase start to build up. The acidity of these enzymes also increases with ripening [65]. In the work of Ketiku [63], about 16 amino acids were identified in unripe and ripe plantain pulp.

Plantains are a rich source of minerals such as iron (Fe), phosphorus (P), potassium (K) and even calcium (Ca). These minerals are essential to proper body function. The mineral concentration of banana fruits varies depending on their geographical location. Works from Hardisson *et al.* [66] and Forster *et al.* [67] showed significant differences in the amounts of K, Mg and P in similar banana spices planted at different locations. This phenomenon was also observed for other minerals such as Fe, Cu, Zn, Ca and Na. Izonfuo and Omuaru [64] observed an increase in the ash and macromineral contents of plantain pulp during ripening. Adeyemi and Oladiji [68] similarly observed an increasing trend in the ash and mineral contents of banana fruits.

The amounts of vitamin A (carotene), vitamin C (ascorbic acid), vitamin B_1, B_2 and B_3 (thiamine, riboflavin and niacin, respectively) and other flavonoids in plantains have been reported to be higher than those in other staples such as yam, cassava and polished rice [69]. Research indicates that flavonoid-rich foods are essential for the control and prevention of chronic diseases like neurodegenerative diseases, cardiovascular diseases, diabetes and cancer [70] [71].

Vitamin C and carotenoids are the two most important vitamins found in significant amounts in plantains [15]. Major carotenoids identified in ripe banana fruits are lutein, α-carotene and β-carotene, most of which are found in the peels and a relatively low amount in the pulp [56] [72] [73] [74]. The content of carotenoids in banana fruits is temperaturedependent. Fruits that are ripened at 35˚C have higher peel carotenoids than those allowed to ripen at lower temperatures, whose carotenoid levels remain fairly constant [75].

Some researchers have indicated that the level of carotenoids increases during maturation and ripening. However, Inocent *et al*. [76] observed higher β-carotene levels in ripe plantains compared to unripe ones. Tones also indicated that cooking methods such as steaming, charcoal roasting and frying significantly reduce the levels of β-carotene and vitamin C in plantains and sweet potatoes. Rojas-Gonzalez *et al*. [77] have also reported the loss of vitamin C in fried plantains. This is expected as vitamin C is a heat-sensitive, water-soluble vitamin [78]. Predictably, the provitamin A content of banana fruits is varied and dependent on the fruit pulp colour [79]. The yellow and orange varieties have recorded provitamin A levels as high as 3500 µg/100g on a fresh weight basis [79]. Other vitamins such as niacin (700 µg), pantothenic acid (370 µg), riboflavin (50 µg) and thiamine (50 µg) have been identified in plantain pulp [6] [8] [45].

The primary acids in banana fruits are ascorbic acid, citric acid, oxalic acid and malic acid. These acids determine the fruit acidity, and it is measured as the Titratable Acidity (TA) or the Total Titratable Acidity (TTA) [80]. The levels of these acids increase during ripening. The combination of the acids and the soluble sugars found in the fruit during ripening contributes to its taste and flavour.

Fresh plantains and banana varieties are also high in moisture. Plantains contain an average of about 65% moisture, compared to 83% for bananas. The high moisture content favours the hydrolysis of the starches into sugars, which also aids the peel inturning yellow [81]. As the moisture content of plantain pulp increases during ripening, there is concomitant moisture loss in the peel. The moisture gain in the fruit pulp during ripening has been attributed to the osmotic pressure associated with different sugar concentrations in the pulp and the peel. The fruit pulp has more sugar than the peel.

5. Post-Harvest Utilisation of Plantain

An average of 40% of plantain produced in West Africa is lost after harvest due to various reasons, which include poor handling, harvesting at late maturity, lack of processing options, contamination, and inadequate storage and transportation facilities [19] [65]. These factors do not only contribute to the increase in post-harvest losses, but they are also associated with quality reduction. Improper handling and transport result in mechanical damage to the fruits. Also, poor storage conditions coupled with high storage temperatures, humidity and a high moisture content of plantains shorten their shelf life, leading to increased rot and waste.

The plantain fruit is used in different traditional dishes and consumed at virtually all stages of maturity (unripe, semi-ripe, ripe, overripe and senescent plantain) by different cooking methods: boiling, steaming, sautéing, frying, roasting and drying [15] [19]. Unripe plantains are boiled and eaten with a sauce, pounded alone or with cassava, and eaten as *fufu* with soup. Semi-ripe and ripe ones are eaten fried, boiled, roasted and even sometimes baked. Thin slices of both unripe and ripe plantains are also fried into chips, both in Nigeria and Ghana.

The bulk nature of plantains and their high perish ability make processing a suitable alternative to extend their shelflife and utilisation. Industrial processing has been limited to making products such as plantain chips and *fufu* flour by small to medium-scale food processors for both the local and export markets. There are other reported uses of plantains, but their commercialization remains in the countries or towns in which they are produced. For example, there are reports of weaning food formulated from plantains with a nutritional composition comparable to any other milk-based weaning food [82]. In Nigeria, ripe plantain pulp has been reported to be used for drinks [64]. Uzogara *et al.* [83] described a fermented drink made from overripe plantains and bananas called *agadagidi*. The overripeplantainsare cut into slices and soaked in water for a maximum of two days, where solubilization and fermentation of the pulp take place. The water, which adopts the colour characteristics of the pulp, is strained, sweetened based on consumer preference, and served as a drink. The drink may also be flavoured and coloured to enhance its sensory properties. The shelf-life of this fermented drink is between 2 and 3 days. However, with the combination of pasteurisation, refrigeration and the addition of chemical preservatives such as sodium benzoate, the shelflife could be extended to about 56 days [84]. Similarly, fermented drinks such as *tonto*, *urwarwa* and *isango* and distilled alcohol *waragi* have been reported from Uganda and Burundi [85] [86] [87]. Other products, such as jam, marmalade and vinegar, have been produced from ripe plantains [88]. Abiodun-Solanke and Falade [89], Adeniji *et al.* [19] and Soto-Maldonado *et al.* [90] have done a detailed review of some other food uses of plantains and bananas. Overripe plantains are useful in preparing traditional foods, which usually take the form of cakes or fritters. Adi *et al.* [91] have studied the variations in some of the native senescent plantain products in terms of processing and their microbial quality. In Ghana, traditional products obtained from overripe plantains include *kaakle*, *kaaklo*, *ofam*, *tatale*, which aresimilar to *dockounou*, a very common meal in Cote d'Ivoire [92] [93]. **Table 1** presents a

Table 1. Categorization of processed plantain products at different ripening stages.

Category	Product	Ripening Stage	Reference
Weaning Food	Extruded plantain/corn/soy weaning food Soybean/maize/plantain mix Cowpea/sorghum/plantain mix Soyamusa (a soybean plantain baby food)	N/A Unripe Unripe Unripe	[94] [95] [82]
Dumplings	Soy-plantain flour for amala Instant plantain flour *Fufu* flour	Unripe Unripe Unripe	[96] [97] [98]
Beverages	*Tonto* (banana or plantain beer) *Waragi* (distilled alcohol) *Agadagidi* (fermented plantain drink) *Urwarwa* *Isango*	Ripe Ripe Overripe Ripe Ripe	[86] [99] [89] [63] [83] [85] [85]
Cakes and Fritters	*Kaakle* Tatale mix Muffins *akpiti, apiti, apitsi, bodongo, akankyie*, or *ofam* *agbetenya* and *kumaku* *tatale* and *kaaklo* *dockounou*	Overripe Ripe Overripe Overripe Overripe	[21] [100] [90] [91] [92] [93]
Chips (Fried)	Chips	Unripe	[101] [102]
Others	Jam, marmalade and vinegar	Ripe	[88]

summary of plantain products. The potential of these products for food security is enormous. Processing convenience forms of these products will enhance the use of underutilised overripe plantains, which go to waste.

Problems associated with the processing of senescent plantain products

The processing of overripe plantain products has not been extensively investigated and documented. Few researchers have attempted to develop shelf-stable alternatives in convenience forms. However, the traditional methods lack standardisation, especially in the flour type and quantity used, cooking time, as well as the amount and type of spices used [91]. This lack of standardisation has been reported to be responsible for the variations in the products from different parts of the country. Standardisation is an important step in food product development. It may require sensory evaluation tools, physicochemical assessments, andoptimisation techniques to obtain the best product. The shelflife of the overripe plantain products is rather short. The product presentation and packaging make it less attractive to the growing middle class.

The microbial profiles of these products have also not been well elucidated. Microbial data are available on similar products in Cote d'Ivoire, *dockounou,* which are cooked either by baking or boiling. Microbes such as aerobic mesophilic bacteria, yeast and moulds, *Enterococci*, *Lactobacilli*, *Bacillus licheniformis* and *Bacillus macerans* were identified. There were no *Salmonella*, *E. coli*, *Staphy-*

*lococcus*or and *clostridium* present in the sample. The microbial profile of this product is an indication of poor hygiene practices in product preparation [92].

Research potential for senescent plantain pulp

According to Aurore *et al.* [8], it is expedient to develop processed products tailored to satisfy contemporary consumer expectations, providing variety and convenience for use by making products that can be used for other product formulations. Minimal processing of fruits and vegetables seems to satisfy the consumer's need for high nutritional quality and convenience products free from additives [103]. There is a potential for storing peeled overripe plantain pulp frozen for subsequent use. Freezing plantain pulp has been reported to yield an undesirable texture after cooking [104]. However, the frozen pulp may be suitable for the indigenous senescent plantain products, which require pureeing. Domestic freezing of ripe plantain pulp is not too popular and has yet to be commercialised. The ripe plantain pulp may either be blanched or glazed with calcium chloride before freezing to enhance its keeping qualities and usage [104].

Studies on the suitability of minimally processed, vacuum-packed ripe plantain pulp have also been underexploited. Vacuum packaging is a kind of modified atmosphere packaging used as a supplement to chilling or freezing to extend the shelf-life of food products while maintaining quality as much as possible [105]. It is one of the flexible packaging methods used to inactivate microorganisms associated with food [106]. The packaged pulp can be used in the bakery industry for bread, muffins, cake and biscuits. It also has the potential for beer, wine and jam production and in smoothies and baby foods similar to the utilisation of bananas [8] [16] [107]. The blanched frozen pulp could also be thawed and pureed for drying. The dried fruit could serve as a fruit bar.

Drying is an alternative shelf-life extension method for the ripe plantain pulp. The earliest research on producing stable ripe plantain products was by Dei-Tutu [100] by drying a batter of ripe plantain and corn dough in a cabinet oven. The challenge in this study was the drying of the overripe plantain/corn dough mixture because of its high moisture and sugar contents. However, indigenous processes require the use of overripe plantains. Etsey *et al.* [108] worked on cowpea fortification of *kaaklo* and *ofam*. Plantains at two different levels of ripeness (soft ripe and hard ripe) and three different cowpea fortification levels (10%, 20%, and 30%) were used. Even though the outcome was beneficial in increasing the protein levels of the snack, the application of the freeze-drying method would make the final product rather expensive. It is noteworthy that a higher score was recorded for all sensory attributes evaluated for soft ripe plantains compared to firm ripe plantains. There is the potential of using the foam-mat drying method to dry the very soft high sugar content overripe plantains into flour for the formulation of a powdered mix. The dried overripe plantain flour has the potential to be used for the processing of traditional snack products such as *zowe*. It can also be incorporated into weaning foods to function as a natural sweetener apart from enriching the meals with macro-minerals (such as Ca, K and F) and vitamin A. Ripe plantain flour has already been used for the production of *fura* with acceptable sensory qualities [109].

6. Adaptable Technologies for Drying Overripe Plantain Pulp

Overripe plantains are difficult to dry using the typical conventional oven and solar drying methods. Pre-drying processing before drying aids in achieving the desired product characteristics [110]. The pre-drying process is quite diverse, and the choice of technique to be employed is influenced by the nature of the drying material. Physical treatments such as blanching and freezing have been used for preparing solid materials before drying [111] [112], while foaming is used for semi-solids and liquids. These physical pre-treatments are aimed at enhancing drying and improving the final quality of the dried material. Depending on the food material and resources available, a combination of these procedures may be needed before drying.

Blanching

Blanching is a mild heat treatment given to food substances without necessarily cooking them, either by steam or boiling water. Apart from leaching some nutrients during blanching, it is a very helpful pre-treatment technique for preparing dried products. The benefits of blanching as a pre-treatment method for drying include the following: inactivation of enzymes such as peroxidase, pectin methlesterase and polyphenol oxidase; changes in tissue structure by loosening the cellular network and separation of the middle lamella; improved rehydration of dried products; improved microbiological quality, improved colour retention, shorter drying time; and increased drying rate.

Foaming

A foam is a colloidal dispersion of gas (internal phase) in a continuous liquid phase (external phase) [113]. In the food matrix, foams are a very complex mixture of gases, liquids, solids and surfactants. They are formed by whipping, beating or shaking [114]. Whipping is commonly done with commercially available mixers. The whipping time and speed affect the foam bubble size, foam density and foam stability, which influence the appearance and textural properties (body smoothness and lightness). However, the foam parameters, such as bubble size, foam density and foam stability, are also affected by the nature of the food material and the foaming agents used for foam formation.

A foaming agent is described as a surfactant material that reduces the surface tension between two liquids or between a liquid and a solid to facilitate foam formation [113]. One important functional property of proteins is their foaming ability. Hence, they are exploited as foaming agents. Protein foaming ability is influenced by its hydrophobic nature and conformational rearrangement, permitting rapid adsorption at the air-water interface, which leads to the formation of a coherent elastic adsorbed layer. The most frequently used foaming agents include gelatin, milk proteins (casein and whey protein), egg white and soy protein. Protein foaming agents can stabilise foams effectively and rapidly at low concentrations. They can also be used over wide pH ranges, which is a reality in various food systems. Protein foaming agents are able to perform in food matrixes with foam inhibitors such as fat, flavour substance and alcohol [113].

Egg white is a natural and readily available food foaming agent with good foaming properties. The chemical composition of egg white is primarily water (88%), with some amount of protein (10.5%). The egg white is also known as albumen and contains as many as 40 different proteins. Moreover, the unique interaction of these proteins is responsible for the foaming ability of egg white, giving it the ability to produce large volumes of stable foam. On whipping, the egg white readily absorbs the air-liquid interface by forming a cohesive viscoelastic film through intermolecular interaction. The major proteins are ovalbumin (~54%), ovomucoid (11%), ovomucin, and lysozyme, conalbumin or ovotrasferrin. The egg white exhibits greater foam volumes, especially at room temperature, and has a shorter whipping time. The presence of sugars improves the stability of egg whites. In situations where the food matrix is not allowing for higher foam stability with egg white, stabilisers may be added to aid foam stabilisation.

Soy protein isolates are obtained from dehulled and defatted soy meal. The protein isolate from soy is highly refined and purified, with a protein content of about 90%. It exhibits functional properties such as emulsification, viscosity, water binding, and dispersibility, in addition to foaming properties.

Various foaming agents are used individually or may be used together with stabilisers such as carboxymethyl cellulose, glycerol monostearate, methylcellulose, carrageenan and xanthan gum. These have been used by researchers to produce heat and mechanically stable foams. The heat and mechanical stability of the foams are essential for effective drying.

Foam properties that influence their drying characteristics include foam density, foam expansion or overrun, foam stability and bubble size. The foam density is the ratio of the foam mass to the foam volume. It is an indication of the extent of whip ability of the foam [115]. The essence of foaming is to lower the density of the drying material to decrease drying time and improve product quality. The density of foams meant for drying has been restricted to values ranging between 0.3 g/cm^3 and 0.6 g/cm^3 [116]. As low densities are required for drying, the foam stability is also vital. The stability of food foams has been measured in several ways. According to Ratti and Kudra [116], foams that do not collapse for at least one hour are mechanically and thermally stable for the entire drying process. German and Phillips [117] determined foam stability by measuring the loss in height and weight of the foam in ambient room over time. Nekrasov *et al.* [118] used a method based on optical measurements to determine the structural parameters of foam (foam stability). Karim and Wai [119] also determined foam stability by measuring the density variation of the foam over a specific time. It was measured directly by draining the continuous phase. Foam stability can also be measured indirectly by determining the change in the bubble size index after storing the foam for 1 hour at 22.8˚C [120].

Combining blanching and foaming

Blanching and foaming are two pre-processing techniques useful in improving the quality of dried products. In the case of overripe plantains, the fruit is high in moisture and sugar. As much as blanching will provide an improved colour and change the tissue structure for good rehydration properties, foaming will also lower the density of the pulp to allow for faster drying. The incorporation of air by whisking will increase the porosity of the blanched plantains for easy moisture escape. The incidence of browning associated with caramelization and maillard browning may be reduced as the drying time is expected to be reduced by blanching and foaming. Blanching and foaming of overripe plantains before drying will help address the challenges associated with conventional hot air drying of untreated overripe plantains, which yield a dark, sticky and chewy material. The stickiness and chewiness associated with the hot air drying of plantains make it impossible to mill into a powder. However, these pre-treatments are expected to ensure a crispy, dried product suitable for powder formation.

Foam-mat drying

The drying of materials that have been foamed during the pre-processing phase of drying is normally referred to as foam-mat drying. According to Ratti and Kudra [116], foam-mat drying is the process of whipping a liquid or semi-liquid into a stable foam before dehydrating it. Foam-mat drying follows a thin layer drying approach, where a thin layer of foam is dried by convective, contact or radiant heat supply. Drying of foams can be achieved by any of the known dryers, such as the cabinet dryer, continuous belt vacuum dryer, microwave-assisted dryer, freeze dryer, microwave freeze dryer and spray dryer. Ratti and Kudra [116] and Sangamithra *et al.* [113] have reviewed the mode of operation of these dryers' use in drying foam mats. Exposing foamed material to relatively high air velocity (45 m/s) will increase the gas-to-material contact area and hasten drying [116]. Foamed materials can also be extruded besides conventional drying.

Foaming of liquids and semi-liquids shortens drying time and improves the quality of dried products [116]. Foaming of agricultural produce prior to drying has been used for heat-sensitive, high-sugar content and viscous foods, which are difficult-to-dry materials and sticky, to obtain products of desirable properties such as good flavour retention, favourable rehydration, and controlled density [116] [121]. According to Ratti and Kudra [116], foam mat-dried products might not always be of superior quality. Especially when compared to drying non-foamed materials by spray drying or freeze drying. However, it will yield a product of better quality than non-foamed substances dried with the aid of a drum, roller dryer or cabinet dryer. In general, the foam-mat drying of any food material is faster than its non-foamed alternative. This has been attributed to the increased interfacial area of foamed material, which causes accelerated liquid (water) transport to the evaporation front. The drying efficiency of foamed substances is better than that of non-foamed materials. The drying efficiency of foamed apple juice was almost two-fold that of non-foamed apple juice, allowing for capital cost savings of 10% [116].

Foam-mat drying is not limited to fruits and vegetables; the technique has been successfully used in drying carrageen [122] [123], egg white [124] and yoghurt [125]. Drying models can test the effectiveness of drying conditions for both foamed and non-foamed materials.

7. Conclusion

Plantains are a potential food security crop as they are available year-round. In West Africa, its culinary applications are at all levels of ripening, contributing to nutrition. The recent battle to minimise food waste, which is threatening the environment due to the emission of methane gases, has called for the valorization of food products. Accordingly, the utilisation of overripe plantains by converting them into diversified minimally processed, processed and ready-to-eat products will help to minimise plantain losses significantly. Packaged and frozen overripe plantain pulp can be further processed into wine, beer, bread, cake muffins and flour. The flour may be suitable for the processing of overripe plantain products such as baby foods and fritters such as *kaaklo*, *ofam*, and *tatale*. Conventional drying of overripe plantains would have produced a sticky mass due to the high moisture and sugar contents. Application of pre-processing techniques such as blanching and foaming before drying will enable successful drying and subsequent pulverisation into powder. While blanching will enhance the product's colour and rehydration properties, foaming will facilitate drying into a glassy state. Plantain in all ripening stages, especially in the overripe stage, holds the potential to address food security globally, especially in plantain-growing areas.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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