CONFERENCE PROCEEDINGS OF THE 1ST INTERNATIONAL BIOECONOMY CONFERENCE (ONLINE)

Theme: Banana and Plantain as Bioresources for Building a Sustainable Circular Economy

Bioeconomy Research Group

Obafemi Awolowo University, Ile- Ife, Nigeria

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Email: bioeconomy@oauife.edu.ng

Editors

Adekunbi Adetola Malomo (Ph.D)
Department of Food Science and Technology,
Obafemi Awolowo University, Ile-Ife, Nigeria

Thomas Adedayo Ayorinde (Ph.D)
National Agency for Biotechnology

Abiola Olaniran Folakemi (Ph.D)
Department of Food Science and Nutrition,
Landmark University, Omu-Aran, Nigeria

Yetunde Adebayo (Ph.D)
College of Federal University of Technology,
Abeokuta, Nigeria

Objective of Circular Economy Research Group

The objectives of the Circular economy research group are to facilitate the exploration of innovative ideas and technologies that harness agriculture for domestic and industrial use, and to create a platform for stakeholders, including researchers, policymakers, industry professionals and innovators, to establish a collaborative network and partnership aimed at implementing and scaling up initiatives that leverage crop, animal and biomass for the circular economy development in West Africa.

Conference Team Outlook

Circular economy research group is made up of staff from the Departments of Microbiology, Sociology, Agricultural and Environmental Engineering, Food Science and Technology, Agricultural Economics, Food and Consumer Science, and Administration from Obafemi Awolowo University, Central Office of Research, Obafemi Awolowo University, Institute of Biotechnology, Institute of Agricultural and Research and Training (IART), Landmark University, Federal University of Agriculture Abeokuta, National Centre for Technology Management (NACETEM) and Pan-Africana Strategic and Policy Research Group (PANAFSTRAG).

Unlocking the potential of biomass-based products stands out as a pathway for establishing a sustainable circular economy. Banana and Plantain have significant nutritional value, yet their huge post-harvest losses present a substantial challenge. Capitalizing on the production of a healthy and sustainable diet and the biomass resources from Banana and Plantain for energy and industrial raw materials has the potential to revolutionize the landscape for stakeholders, policymakers and innovators. It is therefore imperative to thoroughly investigate and discuss the substantial possibilities inherent in Banana and Plantain biomass in West Africa.

The bioeconomy research team in collaboration with the Central Office of Research of Obafemi Awolowo University, Ile-Ife and Pan Africana Strategic and Policy Research group is organizing the first International Conference on Bioresource Potential of Banana and Plantain for Building Sustainable Circular Economy.

The objectives of the conference are to facilitate the exploration of innovative ideas and technologies that harness plantain for industrial use, and to create a platform for stakeholders, including researchers, policymakers, industry professionals and innovators, to establish a collaborative network and partnership aimed at implementing and scaling up initiatives that leverage plantain biomass for the circular economy development in West Africa

I want to appreciate PANAFSTRAG for bringing up the idea of organizing this conference, for their unflinching support, encouragement and love for humanity.

I hereby Welcome everyone; the academia, researchers, students, industrialists, ladies and gentlemen to the international conference on Banana and Plantain as Bioresources for Building a Sustainable Circular Economy

Thank you

Adekunbi Adetola Malomo

Convener

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Usage of Post-Harvest Management Practices among Banana (*Musa paradisica*) and Plantain ((*Musa paradiciaca*) Marketers in Kwara State, Nigeria

[1]Abdulrahman, O. L.,[2] Olatinwo, K. L., [3]Ayanda, I. F., and, [4] Ukpi, S. M. and [5]Shiru M. I.

[1,3 and 4]*Department of Agricultural Economics and Extension Services, Faculty of Agriculture, Kwara State University, Malete, Nigeria.*

[2]*Bioresources Development Centre, Ogbomoso, Oyo State*

Corresponding author: Ukpi, S.M. Email: mngukpi@gmail.com 08038635097

Abstract

This study examined the usage of postharvest management practices among banana and plantain marketers in Kwara State, Nigeria. Snowballing technique was used to generate a sample frame of 320 marketers out of which 75% were randomly selected to make a sample size of 240 respondents for the study. Both interview schedule and key informant interview (KII) were used to gather data. it was then analysed using descriptive and inferential statistics. The leading banana and plantain postharvest management practices were: ripening by covering with leafy/paper/nylon ±2.78, sorting ± 2.73, preservation by hanging in open space ± 2.31, throwing away of unsold ± 2.26, sales within 2 to 3 days ± 2.23, packaging in basket prior transporting ± 2.05, sales under tent ± 1.84 and transportation by motor van ± 1.79. Majority (82.9%) of the respondents had low usage which indicates that the usage of postharvest management practices among marketers was low. Marketers suffered post-harvest losses of banana and plantain by 823 (13.4%) bunches. Results from regression analysis show that losses incurred by respondents along the value chain significantly influenced the usage of postharvest management practices (R^2 =0. 090, F = 7.950, $p < 0.05$). Overall, the losses predict only 9%probability of using postharvest management practices. The study concluded that postharvest management practices were low among banana and plantain marketers in Ilorin Kwara State. The study recommends that there is need for extension service delivery to banana and plantain marketers on improved postharvest management of their goods in reducing high spoilage due to unfavourable weather condition and insect/rodent pest.

Key words: Usage, Post Harvest, Management, Practices, Banana (*Musa paradisica*) Plantain (*Musa paradiciaca*) and Marketers

INTRODUCTION

Banana (*Musa paradisica*) and Plantain (*Musa paradiciaca*) are members of the Musaseae family that originated in Southeast Asia and the Western pacific region (Jatto et al., 2020). And are among the major staple food throughout the humid tropics and developing countries of the world (Hodges et al. 2020; Ajayi and Ayeni, 2019). The Food and Agriculture Organization (FAO) and the International Institute of Tropical Agriculture (IITA) Ibadan, among other research institutions, use the word "banana" to refer to Musa species that are sweet and eaten raw, while "plantain" denotes Musa species that are starchy and requires cooking before consumption (FAO, 2020; Akinyemi et al., 2017). West Africa is one of the major banana and plantain producing regions of the world, accounting for approximately 32% of worldwide production (FAO, 2020). It may interest you that about 87% of banana and plantain grown worldwide are produced by small-scale farmers for consumption and sale to local and regional markets (Gemechu et al., 2021). Apart from their nutritional importance, banana and plantain related enterprise (marketing inclusive) have great prospects in the area of employment generation, contributions to national income and gross domestic product, poverty alleviation, (Chiemela et al., 2021). Postharvest practices and technologies are important to maintain and prolong the shelf life of harvested fruits (Arah et al., 2016). Because of the high demand, banana and plantain marketing business have tracked records of it's great potentials for high economic gain and profitability (Ukwuaba et al., 2022; Agbagwa, Agbugba and Maponya, 2021; Agbugba, 2020). Despite its significant economically and profitable venture, there is still a major challenge of marketing since the fruits are seasonal and highly perishable (Olutomilola, 2021). Also, some constraints include pests and disease, short shelf life, and damage during transportation (Ibidapo and Aladekomo, 2019) The post-harvest wastages of the fruits are quite significant and negatively affect the profit of the marketers (Nkwain et al., 2021). The perishability being experienced by the marketers are mainly caused by mechanical injury during harvesting. It has been reported that the bulk of the postharvest losses of banana/plantain are incurred by the marketers (wholesalers and retailers) during transportation, marketing and sales of the products (Obetta et al., 2020). At marketing stage, in Nigeria, banana and plantain postharvest losses during marketing range from 5% to as high as 40% as reported in previous study by Morris et al., (2019). Although, several studies have been conducted on banana and plantain postharvest management practices (Abdurahman et al., 2019; Obetta and Taru, 2018; Olumba and Onunka, 2020), there is no empirical information on the usage of postharvest management practices of banana and plantain among marketers in Kwara State. This study thus provided answers to the following research questions. i. What is the level of usage of postharvest management practices of banana and plantain in Kwara State?

ii. What is the quantity lost during postharvest management practices of banana and plantain in Kwara State? The main objective of this study is to analyze the usage of postharvest management practices among banana (*Musa paradisica*) and plantain (*Musa paradiciaca*) marketers in Kwara State. The specific objectives are to: i. investigate the level of postharvest practices used by banana and plantain marketers in Kwara State. ii. estimate the quantity of post-harvest losses of banana and plantain in Kwara State;

The hypothesis tested was: Quantity of postharvest loss by the marketers does not significantly determine usage level of postharvest management practices. Specifically, this study is of benefit to the government and agricultural policy makers as it will direct their attention to the available postharvest management practices and how it can be improved upon. Furthermore, this research will also contribute to the marketers' ability to reduce food loss due to proper usage of adequate postharvest management practices.

MATERIALS AND METHODS

Study area

This study was carried out in Kwara State, Nigeria. The population of the study contains all banana and plantain marketers in Kwara State. A multi-stage sampling procedure was used to select respondents. The first stage was the purposive selection of banana and plantain markets in Ilorin. This is because Ilorin consist of 36 largest markets for banana and plantain in Kwara State. In the second stage, a snow balling technique was used to gather the list of 320 marketers in Ilorin metropolis. The third stage involved a random selection of 75% marketers from the list generated. This gave a sample size of 240 marketers for quantitative data while additional ten (10) banana and plantain marketers were interviewed to collect qualitative data on the set objectives of this study. Quantitative data was generated with the use of a well-structured interview schedule through field survey. The interview schedule consists of postharvest practices used by the respondents, quantity of postharvest loss of banana and plantain. Research instruments were prepared and subjected to validity tests. This involved the administration of the interview schedule on respondents outside the study population. The procedure was repeated on the same groups after two weeks and the data collected from the two surveys were subjected to the Pearson Product Moment Correlation analysis. A co-efficient of correlation (r-0.72) was obtained and the instrument was considered reliable. Variables in the study were measured as follows: To identify the level of postharvest practices used by the respondents, a list of postharvest management practices of banana/plantain ranging from cleaning, sorting, packaging, transportation, preservation, ripening, marketing, and processing (Adewoyin et al., 2022) were presented and measured with a four point likert scale. Usage of postharvest practices was assessed based on the number of postharvest practices. Objective 2: Estimating the quantity of loss of plantain and banana among marketers. Quantity of loss was assessed by stage/activities performed by the banana/plantain marketers such as cleaning, sorting, packaging, transportation, preservation, ripening, marketing, and processing. Respondents were asked to first indicate the actual quantity of banana/plantain purchased or harvested per stock/cycle to market. Secondly, respondents were asked to indicate the actual quantity of banana/plantain loss/spoilage in each stage of the marketing processes.

Analysis of data collected from field survey was done using (SPSS) Version 23. Input data were analyzed with descriptive and inferential statistical tools. The inferential statistical tools used were Linear Regression.

RESULTS AND DISCUSSION

Postharvest Management Practices Used by Marketers The postharvest management practices used by banana/plantain marketers were assessed. Results of analysis are presented in Tables below.

Table 2 shows that most of the respondents rarely clean (48.9%) and always sort (72.5%) their banana and plantain after purchase of the products for sale. This implies that cleaning of banana and plantain is not a common practices among the marketers but often sort the products in order to separate bad pieces away from the good ones. This practice could further help the marketers to presents only the good and attractive bunches to attract more customers. This is in line with study by Kamble et al. (2021) that cleaning and sorting of banana and plantain increase consumer acceptance and marketing. The table indicated that motor van ranked 1st,

Table 1: Cleaning and sorting of banana and plantain management practices

Practices	Always used f(%)	Sometimes used f(%)	Rarely used f(%)	Not used f(%)	Mean (SD)
Cleaning	37(15.4)	71(29.4)	116(48.3)	16(6.7)	1.54(.833)
Sorting	174(72.5)	66(27.5)	0	0	2.73(.447)

Source: Field survey, 2022

Tricycle 2nd, bicycle/motorbike 3rd, while the use of head pan 4th position respectively. This finding indicated that motor van (vehicle), tricycle and motorbike were the topmost means

Table 2: Transportation Medium of Banana/Plantain

Mode of transportation	Always used f(%)	Sometimes used f(%)	Rarely Used f(%)	Not used f(%)	Mean(SD)	Ranking
Vehicle	119(49.6)	30(12.5)	12(5.0)	79(32.9)	1.79(1.351)	1st
Tricycle	44(18.3)	59(24.6)	42(17.5)	95(39.6)	1.22(1.155)	2nd
Bicycle/motorbike	34(14.2)	24(10.0)	13(5.4)	169(70.4)	0.68(1.128)	3rd
Head pan	13(5.4)	18(7.5)	55(22.8)	154(64.2)	0.54(.852)	4th

Source: Field survey, 2022

of transporting banana and plantain to place of sale by the marketers in Ilorin. This is in line with report by (Ayanwale et al., 2018) who found that majority of plantain marketers transport their goods by vehicle.

Table 3: Preservation Methods Used by Respondents

Practices	Always used f(%)	Sometimes used f(%)	Rarely used f(%)	Not used f(%)	Mean(SD)	Ranking
Hanging in openspace	130(54.2)	67(27.9)	30(12.5)	13(5.4)	2.31(.890)	1st
Under tree shade	81(33.8)	116(48.3)	28(11.7)	15(6.3)	2.10(.835)	2nd
Clay pot	32(13.3)	18(7.5)	25(10.4)	165(68.8)	0.65(1.087)	3rd
Fridge/deepfreezer	16(6.7)	30(12.5)	25(10.4)	169(70.4)	0.55(.949)	4th
Evaporating Cooling System	0	0	0	100	0.0	5th

Source: Field survey, 2022

The table above, indicated that hanging in open space (mean=2.31) ranked 1st, placing banana and plantain under tree shade 2nd, use of clay pot (mean= 0.65) 3rd, the use of Fridge/deep freezer 4th and there is zero usage of (ECS). This finding implies that evaporating cooling system (ECS) is not known amongst banana and plantain marketers in kwara state. They use clay pots instead.

Table 4: Level of Postharvest Management Usage

Obtained score	Level	Frequency	Percentage	Mean obtained score
43 – 84	High	41	17.1	
0 – 42	Low	199	82.9	36.4
Total		240	100	

Minimum - Maximum possible score = 0 – 84point

Table 5: Quantity of Losses at Different Postharvest Stage (Bunches)

Quantity of lost at different postharvest stage (bunches)	Total loss f total (Freq.)	Percentage stockloss of total stock (%)	Mean	SD	Ranking
Ripening	298	4.8	1.24	0.709	1st
Marketing days to finish selling ripened banana/plantain	193	3.1	0.80	0.672	2nd
Transportation	190	3.1	0.79	0.827	3rd
Preservation	43	0.7	0.18	0.384	4th
Packaging for transport	33	0.5	0.14	0.345	5th
Place to sell/display ripened banana/plantain:	30	0.5	0.13	0.331	6th
Sorting	18	0.3	0.08	0.264	7th
Cleaning	18	0.3	0.08	0.264	7th
Processing of unsold	0	0.0	0.00	0.000	
Total	823	13.4			Low

Source: Field survey, 2022

Criteria: 1 – 30% = Low loss; 31 – 59% = Moderate loss; 60 – 100% = High loss

The aggregate usage level of banana and plantain by the marketers is presented in Table 7. It shows that 82.9% of the respondents had low usage scoring between 0 to 42 points while 17.1% had high usage scoring between 43 to 84 points. This indicates that the use of postharvest management practices among banana and plantain marketers is low. This finding agrees with report by Morris et al. (2019) who found that plantain marketers in Rivers State have poor usage of postharvest management practices.

Result presented in Table 8 shows that the aggregate quantity loss of banana and plantain per cycle stock of the marketers was 823 bunches which account for 13.4% total lost. This quantity is higher than 5.0% of banana and plantain postharvest lost reported by Olayemi et al. (2012) and lower than 40% as reported by Olorunda and Aworth (2020). Specifically, Table 13 further shows that 298 bunches (4.8%) quantity lost occurred during ripening stage, 193 bunches (3.1%) quantity lost occurred during the space of marketing days to finish selling ripened banana/plantain, 190 bunches (3.1%) quantity lost occurred during transportation of the product from purchasing site to place of sale, 43 bunches (0.7%) quantity lost occurred 65 during preservation stage, 33 bunches (0.5%) quantity loss occurred during packaging for transport, 30 bunches (0.5%) quantity lost occurred due to nature of place to sell/display ripened banana/plantain, 18 bunches (0.3%) quantity lost occurred during cleaning and sorting respectively while no lost was recorded during value addition to unsold products. These findings shows that highest level of lost occur during ripening stage, followed by days to market ripened banana/plantain followed by lost incurred during transportation.

Result from regression analysis in Table 9 shows that losses incurred by respondents alongthe value chain significantly influenced the usage of postharvest management practices (R^2 = 0. 090, F = 7.950, $p < 0.05$). For overall, the losses predict only 9%probability to use postharvest management practices. The coefficient of losses incurred during ripening (B = -0.660; p <0.05) and marketing days to finish selling ripened banana/plantain (B = -0.995; p <0.05) indicated inverse significance. This indicates that there was a negative relationship between losses incurred during ripening and number of marketing days to finish selling ripened banana/plantain. By implication, an increased number of losses incurred during ripening and numbers of days to sell the ripe banana and plantain will lead to a marginal increase in the usage of postharvest practices in reducing losses by 0.660 units and 0.995 units respectively.

Hypothesis of the Study

H01: Postharvest Management Practices Used Do Not Significantly Determine the Quantityof Potharvest Loss by the Marketers.

Table 6: Results of linear regression showing losses that contributed to usage ofpostharvest management practices

Use of postharvest management Practices	B	Std. Error	t-statistic	Sig. (p-value)
(Constant)	5.672	.261	21.736	.000
Cleaning	.339	.207	1.637	.103
Sorting	.099	.325	.306	.760
Packaging for transport	-.525	.486	-1.081	.281
Transportation	.148	.191	.774	.440
Preservation	.107	.198	.537	.592
Ripening	-.660	.325	-2.031	.043*
Place to sell/display ripened banana/plantain	-.297	.619	-.480	.632
Marketing days to finish selling ripened banana/plantain	-.995	.493	-2.018	.045*

Model Summary
R = 0.300
R square = 0.090 = 9% Adjusted R square = 0.058
Std. Error of the Estimate = 1.66986F-statistics = 7.950
Sig. = 0.005

SUMMARY CONCLUSION AND RECOMMENDATIONS

Summary

This study analyzes the usage of postharvest management practices among plantain and banana marketers in Kwara State, Nigeria. Specifically, the study examined the level of postharvest practices used by plantain and banana marketers in Kwara State, and estimated the quantity of postharvest losses of plantain and banana in Kwara State. One hypothesis was formulated and tested to authenticate the results of the study. Snowball sampling technique was used to generate a frame of 320 marketers for the study. The instruments used for data collection were: structured questionnaire, administered through field survey. Data collected through these methods were analysed using descriptive statistics to address the research objectives, while linear regression was used for the hypothesis. Findings on the postharvest management practices used by marketers, 48.3% rarely clean their banana and plantain after purchase while 72.5% always sort the banana and plantain after purchase. Findings show that packaging prior transporting in basket ± 2.05 ranked 1st, hanging in open space as preservation method ± 2.31 ranked first, cover with leafy/paper/nylon materials as ripening method ± 2.78 ranked first, Marketers suffered post-harvest losses of banana and plantain with 823 (13.4%) bunches. Of the percentage losses, 298(4.8%) bundles were loss during ripening stage, 193 (3.1%) bundles were loss during the space of marketing days to finish selling ripened banana/plantain, 190 (3.1%) were loss during transportation of the product from purchasing site to place of sale. On hypothesis of the study, For overall, the factors predict 80.3% of marketers towards the usage of postharvest management practices. Linear regression analysis also indicated that losses incurred during ripening and marketing days to finish selling ripened banana/plantain significantly influenced the usage of postharvest management practices. For overall, the losses predict only 0.09% probability to use postharvest management practices. Based on conclusion drawn from the findings, the following recommendations were made: Banana and plantain marketers who are non-members of cooperative group should be organized into cooperative society for receiving vital information from government institutions and non-governmental organizations on banana and plantain marketing. this study suggests that the

marketers should utilize the unsold for Dodo Ikire. Where the banana/plantain has spoiled beyond processing it for Dodo Ikire, the marketers can use it to make fertilizer.

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Studies on the Fortification of maize-ogi with ripe and unripe banana

Ojoawo*[1], L.S. and Taiwo[1], K.A. *Department of Food Science and Technology, Obafemi Awolowo University, Osun State, Nigeria*

Corresponding author: ojoawolydia@gmail.com

Abstract

Efforts to address nutritional deficiencies have included nutritional supplementation and fortification of staple foods, particularly using natural food sources. This project aimed to fortify maize ogi with banana blends (Cavendish banana at the second and fourth stages of ripeness) to enhance nutritional value and sensory properties. Maize and bananas were processed into powder and mixed in ratios of 80% ogi: 20% unripe or ripe banana. Functional analyses, including bulk density, swelling power, and oil absorption capacity, were conducted. Antioxidant properties were evaluated using DPPH (UR80: 38.96%) and metal chelating assays. Proximate and mineral analyses showed a significant increase in calcium (UR80: 61.30 mg/100g). Sensory evaluation indicated that the UR80 sample, with improved viscosity and stability, was highly rated for texture and taste. This study concludes that fortification of ogi with ripe and unripe offers a nutritious, sugar free option for vulnerable groups like infants and the elderly.

Keywords: Cavendish banana; Maize ogi; Fortification; Antioxidant properties; Sensory evaluation.

Introduction

In Nigeria, locally formulated diets such as maize ogi, a fermented cereal porridge, are a common food for infants, young children, and the elderly. However, maize ogi is often low in essential nutrients, particularly protein, vitamins, and minerals. To address these nutritional deficiencies, there has been a growing interest in fortifying foods with natural sources, and banana has emerged as a promising option for fortification due to its rich nutritional profile (Adeyemi and Umar, 1994).

Bananas, especially the Cavendish variety, are rich in potassium, calcium, iron, fiber, and antioxidants (Davey *et al.*, 2007). The ripeness of the banana plays a crucial role in its nutritional value. Unripe bananas (second stage of ripeness) contain high amounts of resistant starch, which aids digestion and regulates blood sugar levels, making them a healthier option for fortification (Englyst *et al.*, 1992). On the other hand, ripe bananas (fourth stage of ripeness) are rich in simple sugars, providing a natural source of energy. Both ripe and unripe bananas bring unique benefits to food fortification, contributing to texture, flavor, and nutritional value (Robinson and Sauco, 2010).

To effectively utilize bananas for food fortification, pre-drying techniques such as blanching and controlled drying temperatures are essential. Blanching, a mild heat treatment, helps preserve the color, texture, and nutrient content of the bananas by inactivating enzymes that cause browning and spoilage (Mazza, 1983). Following blanching, the bananas are dried using cabinet drier at temperatures ranging from 40-45°C. The drying process removes moisture, thereby increasing the shelf life of the bananas and making them suitable for flour production (Taiwo *et al.*, 2009). In this study, the bananas were dried and milled into fine flour to blend with maize ogi in specific ratios (80% maize ogi: 20% unripe banana, 80% maize ogi: 20% ripe banana). This pre-drying treatment ensures that the banana flour retains its functional and nutritional properties during storage and use.

The preparation of maize ogi flour involves soaking, fermenting, and drying maize grains. The grains are first soaked in water to initiate the fermentation process, which typically lasts 5 days. Fermentation not only enhances the flavor and texture of ogi but also improves its nutritional value by breaking down antinutrients and increasing bioavailability of minerals. After fermentation, the maize is wet milled, filtered to remove the bran and germ, and dried into a fine powder. This ogi powder serves as the base for blending with banana flour to create a fortified product. Banana fortification has the potential to improve both the nutritional and functional properties of maize ogi. Studies have shown that banana blends can enhance the texture, viscosity, and overall acceptability of fortified foods (Juliano *et al.*, 2009). The functional properties of food ingredients, including water absorption capacity, oil absorption capacity, and swelling power, are crucial to determining the quality and consumer appeal of fortified products (AsifUlAlam *et al.*, 2014). Additionally, the rehydration properties of the ogi, which is typically reconstituted with water before consumption, play a key role in its sensory characteristics (VegaGalvez *et al.*, 2009).

This study aims to investigate the effect of fortifying maize ogi with Cavendish banana flour at different stages of ripeness. By analyzing the functional, physicochemical, and sensory properties of the fortified maize ogi, the research seeks to create a more nutritious and sensory appealing product suitable for vulnerable populations such as infants and the elderly. The findings of this study will contribute to the development of the fortification maize ogi with banana a healthier and more sustainable alternative to traditional ogi.

2 Materials

Banana fruits (*Musa acuminata Cavendish*), both unripe (at the second stage of ripeness, green) and partially ripe (at the fourth stage of ripeness, yellow), along with yellow maize, were sourced from University Teaching and Research Farm, Obafemi Awolowo University, Ile-ife, Osun State, Nigeria. for use in this research.

Preparation of Cavendish Banana Flour

Cavendish bananas, both unripe (second stage of ripeness, green) and partially ripe (fourth stage of ripeness, yellow), were used for this study. The bananas were peeled and sliced into 1 cm thick pieces. To prevent enzymatic browning in the yellow bananas (fourth stage), the slices were dipped in a 1% sodium meta bisulphite solution for 5 minutes. Both green and yellow banana slices were dried in a cabinet dryer at 40-45°C until the slices were completely dry. The dried banana slices were milled using a laboratory hammer mill and then sieved twice through a 250 µm mesh sieve. The resulting banana flour was stored in airtight polyethylene bags at room temperature until further analysis.

2.2 Preparation of Maize Ogi Flour

Yellow maize was used to prepare Ogi flour following the traditional wet milling method as modified by recent studies (Oluwajoba *et al*., 2020). Yellow maize was soaked in distilled water for 5 days at room temperature (28 ± 2°C) to ferment. The soaked maize was wet milled and the resulting slurry was sieved through muslin cloth to remove husks. The wet Ogi slurry was allowed to settle, and the water was decanted. The sediment was dried in a cabinet dryer at 45-50°C until fully dry. The dried Ogi was milled into fine powder and stored in airtight polyethylene bags for further use.

Measured Variables

Various functional, physicochemical, and sensory properties of the Ogi-banana flour blends were analyzed. This included bulk density, pH, titratable acidity (TTA), water absorption capacity (WAC), oil absorption capacity (OAC), spreadability, viscosity, swelling power, least gelation concentration, color determination, antioxidant properties, proximate composition, and pasting properties.

Bulk Density

Bulk density was determined using the method described by Siddique *et al.* (2010). A 10 ml graduated cylinder was filled with the sample and tapped 50 times to eliminate air spaces. The weight of the sample was recorded, and bulk density was calculated as the weight per unit volume (g/ml).

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{volume\ of\ samplemafter\ trapping\ (mL)} \quad (1)$$

pH and Titratable Acidity (TTA)

The pH of the sample was determined by making a 10% (w/v) suspension of the flour sample in distilled water. The suspension was stirred for 10 minutes, and the pH was measured using a calibrated pH meter (AOAC, 2020). Titratable acidity was assessed by titrating the flour suspension with 0.1M NaOH using phenolphthalein as an indicator. The titratable acidity was calculated as a percentage of lactic acid.

$$\text{Average pH} = \frac{pH_1 + pH_2 + pH_3}{3} \quad (2a)$$

Where; pH_1 = pH value 1; pH_2 = pH value 2; pH_3 = pH value 3;

$$\text{Average titre value} = \frac{T_1 + T_2 + T_3}{3} \quad (2b)$$

$$\%\ \text{Lactic acid} = \frac{\text{Volume of NaOH used} \times 0.1\text{N} \times \text{Equivalent weight of lactic acid}}{weight\ of\ ogi\ slurry} \times 100 \quad (2c)$$

Where; T_1 = Titre value 1; T_2 = Titre value 2; T_3 = Titre value 3;

Volume of NaOH used; NNoH=Normality of NaOH solution $ofNaOHsc$. Mill equivalent factor for lactic acid =0.09

Water Absorption Capacity (WAC)

The water absorption capacity of the Ogi banana flour blends was determined following the method of Malomo *et al.* (2012). A 1 g sample was mixed with 10 ml of distilled water and allowed to stand for 30 minutes. After centrifugation at 4000 rpm for 20 minutes, the supernatant was decanted, and the weight of the water absorbed by the sample was recorded.

Oil Absorption Capacity (OAC)

Oil absorption capacity was determined using the method of Appiah *et al.* (2011). A 1 g sample was mixed with 10 ml of vegetable oil and allowed to stand for 10 minutes. After centrifugation at 2000 rpm for 30 minutes, the excess oil was decanted, and the weight of the absorbed oil was recorded.

Spreadability and Viscosity

Spreadability of the reconstituted Ogi samples was measured using a spreadability machine. 20 g of Ogi flour was reconstituted with hot water at varying volumes (160 ml, 200 ml, 240 ml, and 280 ml) until the desired consistency was achieved. Spreadability was measured by allowing the paste to spread on the machine and measuring the diameter of the spread. Viscosity was determined using a Brookfield Viscometer at 80°C for hot paste and 30°C for cold paste.

$$\text{Spreadability (cm}^2\text{)} = \frac{d^2 \times \pi}{4} \quad (3)$$

Swelling Power

Swelling power was measured according to the method of Takashi and Sieb (1988). A 1 g sample was heated with 10 ml of water at 60°C and 80°C for 30 minutes. After centrifugation, the supernatant was discarded, and the swollen granules were weighed to calculate the swelling power.

Least Gelation Determination

The least gelation concentration of the Ogi banana flour blends was determined using the method of Sathe and Salunkhe (2004). Suspensions of 220% (w/v) were prepared in distilled water and heated in a boiling water bath for 1 hour. The test tubes were then cooled, and the least gelling concentration was noted as the minimum concentration at which the sample did not slip when inverted.

Colour Determination

The color of the Ogi banana flour blends and reconstituted Ogi samples was measured using a colorimeter, following the method outlined in recent studies (Adeyemi & Olusola, 2021). The flour and paste samples were placed on a white background and color measurements (L, a, and b values) were recorded using a colorimeter app.

DPPH Assay

The DPPH radical scavenging activity was determined using the method described by Girgih *et al.* (2011). The flour samples were mixed with 0.3 mM DPPH in methanol, and the absorbance was measured at 517 nm after 30 minutes. The percentage of inhibition was calculated to determine the antioxidant activity.

$$\text{DPPH(\%)} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}}\ 100$$

(4)

Metal Chelating Activity

The metal chelating activity was determined using the method described by Xie *et al.* (2008). The ability of the samples to chelate ferrous ions was measured by mixing the sample with 2 mM FeCl2 and 5 mM ferrozine. The absorbance was read at 562 nm, and the percentage of metal chelating activity was calculated.

$$\text{Metal chelating activity (\%)} = \frac{(Ab - As)}{Ab} \times 100 \quad (5)$$

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Total Phenolic Content (TPC)

The total phenolic content was determined using the Folin–Ciocalteu method (Gulcin *et al.*, 2003). The samples were mixed with Folin-Ciocalteu reagent and sodium carbonate solution. After incubation, the absorbance was measured at 760 nm, and the results were expressed as milligrams of gallic acid equivalents (GAE) per gram of the sample.

Mineral Content Determination

Mineral content analysis was conducted using standard AOAC, 2016 methods. The samples were first digested with a mixture of concentrated nitric acid and perchloric acid. Calcium (Ca), iron (Fe), potassium (K), and sodium (Na) were quantified using atomic absorption spectrophotometry (AAS). The concentrations of these minerals were measured in mg/100g of the sample. For calibration, standard solutions of known mineral concentrations were prepared, and the absorbance of each sample was compared to the standard curves to determine the mineral concentrations in the samples. All analyses were performed in triplicate to ensure accuracy and precision.

Proximate Composition Determination

Proximate composition analysis was performed using standard (AOAC, 2005) methods. Moisture content was determined by drying samples at 105°C until a constant weight was achieved. Protein content was measured using the Kjeldahl method, while crude fat was determined using Soxhlet extraction. Ash content was measured by ashing samples in a muffle furnace at 550°C. Carbohydrate content was calculated by difference. Mineral content, including calcium, iron, potassium, and sodium, was analyzed using atomic absorption spectrophotometry (AAS) following AOAC (2010) procedures.

Pasting Properties

The pasting properties of the Ogi banana flour blends were determined using a Rapid Visco Analyser (Newport Scientific Pty Ltd., Australia). The analysis involved heating the flour suspensions from 50°C to 95°C, holding at 95°C for 5 minutes, and then cooling to 50°C. The pasting viscosity was recorded in rapid viscosity units (RVU). (Newport Scientific, 1998).

Sensory Evaluation

A sensory evaluation was conducted with a panel of 20 trained ogi consumers to assess the sensory attributes of maize ogi fortified with ripe and unripe bananas. The samples included traditional maize ogi (OGC), ogi fortified with 80% ogi and 20% ripe banana (RB80), 80% ogi and 20% unripe banana (UR80), 90% ogi and 10% ripe banana (RB90), and 90% ogi and 10% unripe banana (UR90). The ogi samples were reconstituted into porridge and served hot on randomly coded plates. The panelists rated attributes such as color, flavor, texture, and overall acceptability using a 7-point hedonic scale, where 7 represented 'like extremely' and 1 represented 'dislike extremely.' The mean scores for each sample were calculated and reported as described by Orekoya (2017).

Statistical Analysis

All experiments were conducted in triplicate, and the data obtained were analyzed using one way analysis of variance (ANOVA). Significant differences between means were determined using Duncan's multiple range test at a significance level of $p < 0.05$.

Results and Discussion

Bulk Density

The bulk density of the fortified ogi-banana flour samples ranged from 0.57 g/ml to 0.63 g/ml. The control sample (OGC) had the highest bulk density (0.63 g/ml), while the unripe banana blend (URC) had the lowest (0.57 g/ml). The slight decrease in bulk density with banana flour addition suggests that banana flour has a lighter structure compared to maize ogi flour, making the blends less compact. All values are within acceptable limits for storage and packaging. As shown in Table 1

Table 1: Effect of Banana Addition on Bulk Density and Oil Absorption Capacity (OAC) of Maize-Ogi

Sample	Oil Absorptions (%)	Bulk Density (g/ml^3)	Average TTA
OGC	148.34	0.65	5.2
RBC	130.66	0.54	1.20
UBC	133.56	0.46	2.35
RB80	127.45	0.61	5.00
UR80	129.07	0.51	4.35

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; URC: Unripe Banana Control; UR80: 80% Ogi: 20% Unripe Banana.

Oil Absorption Capacity (OAC)

The oil absorption capacity of the samples ranged from 105% to 130% shown in Table 1 above. The ripe banana blend (RB80) had the highest OAC (130%), indicating better oil retention compared to the control (OGC), which had the lowest OAC (105%). This suggests that banana flour fortification enhances the fat-binding ability of ogi, potentially improving the mouthfeel and flavor retention of the product. Chandra and Samsher (2013) reported similar findings, where the addition of banana flour to food products increased oil absorption capacity, enhancing the product's texture and palatability. The observed increase in OAC in this study is consistent with their results, further supporting the use of banana flour as a functional ingredient in improving the quality of cereal-based foods.

pH and Titratable Acidity (TTA)

The pH values of the fortified maize ogi samples, as shown in Table 2, ranged between 3.52 and 4.25. Among the samples, the unripe banana blend (UR80) recorded the lowest pH value of 3.52, indicating a more acidic nature compared to the other formulations. In contrast, the control sample (OGC), which contains no banana fortification, exhibited the highest pH value of 4.25. Akingbala *et al.* (2005) reported increased acidity in products when fruit flour was added, noting that the increased acidity could enhance shelf stability and impart a desirable tartness.

Similarly, the titratable acidity (TTA) results shown in Table 1 mirrored the trend observed in the pH values. The UR80 sample had the highest TTA of 0.76%, indicating a higher total acid concentration. On the other hand, the control sample (OGC) showed the lowest TTA at 0.42%. Adeyemi *et al.* (2008) demonstrated that fruit fortification tends to increase acidity, which can improve shelf life and flavor, reflecting the differences in acid concentration among the samples in this study.

Table 2: Effect of Banana Addition on pH and Titratable Acidity (TTA) of Maize-Ogi

Sample	Water ratio (ml)	Mean pH (Reconstituted)
OGC	1:4	3.92
	1:5	3.92
	1:6	3.89
	1:7	3.90
RB80	1:4	4.42
	1:5	4.34
	1:6	4.36
	1:7	4.40
UR80	1:4	4.48
	1:5	4.46
	1:6	4.45
	1:7	4.49

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; URC:

Unripe Banana Control; UR80: 80% Ogi: 20% Unripe Banana

Water Absorption Capacity (WAC)

The water absorption capacity (WAC) of the fortified ogi-banana flour shown in Figure 1 ranged from 150% to 190%. The unripe banana blend (UR80) exhibited the highest WAC at 190%, while the control sample (OGC) showed the lowest at 150%. Mepba *et al.* (2007) showed that adding banana flour increased water absorption capacity in various food products, which is important for enhancing the final texture. When analyzing the relationship between water absorption and temperature, we fit the data using regression models. For the control sample, the regression equation $y=2.3325x^2+21.976x+19.713$ with an R^2 value of 0.9977.had an R^2 value of 0.9977 shown in Table 3.3, indicating a very strong fit and that the water absorption in the control sample increased predictably with temperature. For the fortified samples, the models also showed a strong fit, with R^2 values ranging from 0.9604 to 0.9907, demonstrating the consistency of the water absorption patterns with temperature variations.

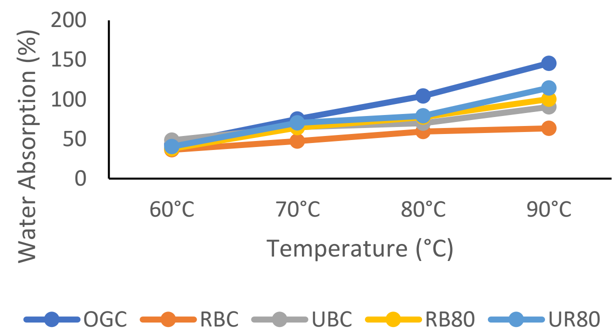

Figure 1: Effect of Banana Addition on Water Absorption Capacityty (%) of Maize Ogi Flour

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; URC: Unripe Banana Control; UR80: 80% Ogi: 20% Unripe Banana

Spreadability and Viscosity

The spreadability of the reconstituted fortified ogi samples shown in Figure 2 ranged from 25 cm^2 to 30 cm^2, with the unripe banana blend (UR80) exhibiting the highest spreadability. This result indicates that UR80 is more suitable for producing smooth-textured porridge. The control sample (OGC) showed the lowest spreadability (25 cm^2). Similarly, Fagbemi and Oshodi (1991) observed increased viscosity in plantain-fortified flour blends, corroborating the increase seen with the UR80 blend in this research. When fitting the spreadability data to a polynomial regression model shown in Table 3.4, the equation $y=0.66x^2+32.598x+12.545$, R^2 = 0.9994 was obtained for the Ogi control sample and ($y=5.8275x^2 5.7925x+55.338$, yielding an R^2 value of 0.9888, for the fortified sample with ripe banana (RB80) signifying an excellent fit and demonstrating a consistent increase in spreadability with increasing water volume.

The viscosity of the samples shown in Figure 3 varied as well, with UR80 showing the highest viscosity at 50,000 cP, compared to the control sample (OGC) which had the lowest viscosity at 37,000 cP. A regression model applied to the viscosity data for the fortified samples shown in Table 3.5 resulted in the equation $y=25.2x^2-1905.3x+14190$ with an R^2 value of 1 indicating a strong fit. This relationship shows that banana fortification significantly impacts the thickness and consistency of the product, enhancing its texture and making it more viscous compared to the control.

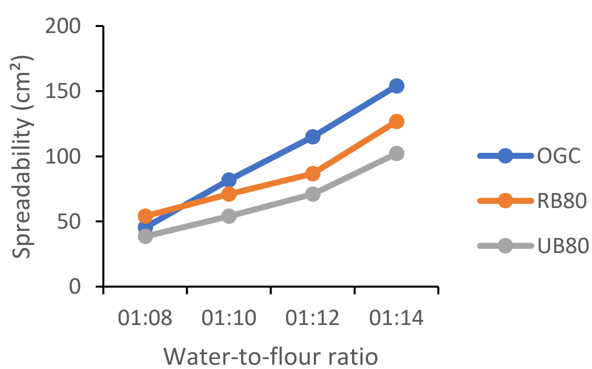

Figure 2: Effect of Banana Addition on Reconstitution Properties (Spreadability) of Maize Ogi Flour

OGC: Ogi Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

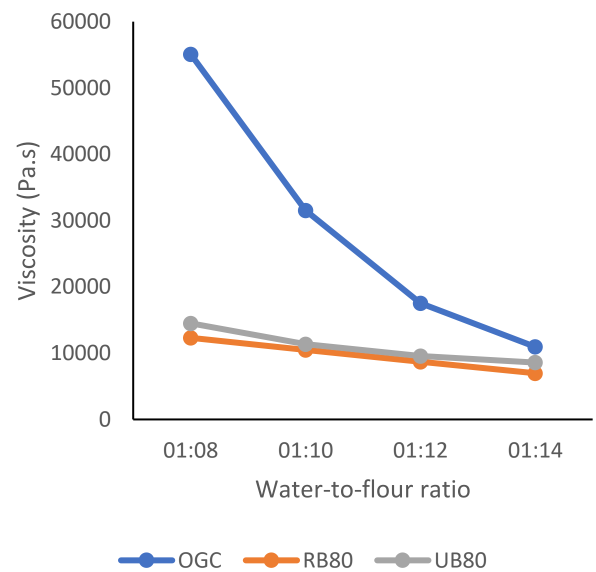

Figure 3: Effect of Banana Addition on Reconstitution Properties (Viscosity) of Maize Ogi Flour

OGC: Ogi Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

Swelling Power

The swelling capacities of maize ogi samples at different temperatures (60°C, 70°C, 80°C, and 90°C) demonstrate the effect of banana fortification on water absorption shown in Figure 4. The control sample (OGC) without banana fortification exhibited the highest swelling capacity across all temperatures, peaking at 2.30 at 90°C, attributed to the high amylopectin content in maize starch (Adeyemi and Soluade, 1993). In contrast, the ripe banana-fortified sample (RBC) showed the lowest swelling capacity (0.90 at 90°C) due to higher soluble sugars and lower resistant starch in ripe bananas, reducing water absorption (Juliano *et al.*, 2009). The unripe banana-fortified sample (UBC) had a higher swelling capacity than RBC but was still lower than OGC, influenced by the high resistant starch content in unripe bananas (Wang *et al.*, 2012). Intermediate swelling capacities were observed in samples fortified with different proportions of bananas (RB80 and UR80), indicating a balance between maize starch and banana components. Polynomial regression models for these samples revealed a strong correlation between temperature and swelling capacity, with R^2 values close to 1. For example, the regression model for OGC shown in Table 6 is $y=-2E{-}15x^2 +0.45x+0.5$ ($R^2 = 1$), indicating an excellent fit and predictability of swelling behavior as temperature increases. Similarly, the RBC sample showed a regression model of $y=0.0025x^2 +0.1345x+0.3225$ ($R^2 = 1$), confirming a consistent decrease in swelling capacity with temperature. The models for RB80 and UR80 also demonstrated high predictability with equations $y=0.01x^2 +0.238x+0.59$ ($R^2 = 0.9998$), $y=0.0125x^2+0.1725x+0.3125$ ($R^2 = 0.9995$) respectively. This strong correlation indicates that the fortification of maize ogi with bananas affects its swelling properties in a predictable manner.

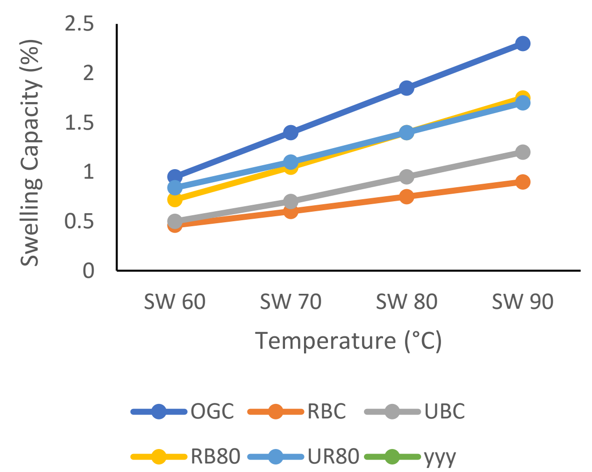

Figure 4: Effect of Banana Addition on on Swelling Capacity (%) of Maize Ogi

OGC: Ogi Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

Table 3: The Regression Equation for Effect of Fortification on Water Absorption Capacity (%) of Maize Ogi Flour

Sample	Regression Model	R^2 Value
OGC	y=2.3325x2+21.976x+19.713	0.9977
RBC	y=−1.8225x2+18.463x+19.238	0.9906
UBC	y=0.9625x2+8.2885x+40.583	0.9906
RB80	y=38.234x0.6863	0.9907
UR80	y=40.705x0.7065	0.9673

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Table 4: The Regression Equation for Effect of Fortification on Viscosity of Maize Ogi Flour

Sample	Regression Model	R^2 Value
OGC	$y=-4250.2x^2 - 35895x + 86642$	0.9998
RB80	$y=25.2x^2 - 1905.3x+14190$	1
UB80	$y = -4319\ln(x) + 14437$	0.9979

OGC: Ogi Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

Table 5. The Regression Equation for Effect of Fortification on Spreadability of Maize Ogi Flour

Sample	Regression Model	R^2 Value
OGC	$y=0.66x^2 + 32.598x +12.545$	0.9994
RB80	$y=5.8275x^2 - 5.7925x+55.338$	0.9888
UB80	y=28.016e0.3196x	0.9971

OGC: Ogi Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

Table 6. The Regression Equation for Effect of Fortification on Swelling Capacity of Maize Ogi Flour

Sample	Regression Model	R^2 Value
OGC	$y=-2E-15x^2 +0.45x+0.5$	1
RBC	$y=0.0025x^2 +0.1345x+0.3225$	1
UBC	$y=0.005x^2 +0.319x+0.395$	1
RB80	$y=0.01x^2 +0.238x+0.59$	0.9998
UR80	$y=0.0125x^2+0.1725x+0.3125$	0.9995

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana

Least Gelation Concentration

The least gelation concentration (LGC) shown in Table 3.7 ranged from 8% to 14%, with the control sample (OGC) requiring the highest concentration for gel formation (14%), while the unripe banana blend (UR80) had the lowest (8%). This indicates that the addition of banana flour improves the gelling properties of ogi, potentially enhancing the texture of the final product. Otegbayo *et al.* (2018) investigated the functional properties of composite flours made from plantain and maize and found that the inclusion of plantain flour significantly lowered the LGC of the blends, indicating enhanced gelation characteristics. This is similar to the results in this study, where the addition of unripe banana flour (UR80) to maize ogi resulted in a lower LGC of 8%, suggesting improved gel-forming capacity.

Colour Determination

The color analysis of the flour blends shown in Table 8 showed variations in lightness (L), redness (a), and yellowness (b). The ripe banana blend (RB80) had the highest yellowness (b value), indicating a more vibrant yellow hue, while the control sample (OGC) had a relatively duller appearance. For instance, Adepoju *et al.* (2021) evaluated the impact of adding pumpkin flour to maize ogi and observed a significant increase in yellowness (b value) in the fortified blends. The color change in fortified samples is due to the natural pigments in bananas, which can improve the visual appeal of the product.

Table 3.7: Effect of Banana Addition on on Least Gelation Concentration of Maize Ogi

Con/Sample (%)	OGC	RBC	UBC	RB80	UR80
1	+	-	-	+	+
3	+	+	+	+	+
5	+	-+	-+	-+	+
7	+	-+	-+	-+	+
9	+	-+	-+	-+	+
11	+	+	+	+	+
13	+	+	+	+	+
15	+	+	+	+	+
17	+	+	+	+	+
20	+	+	+	+	+

Note: - not gelled ; -+ partially gelled ++ gelled

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Antioxidant Determination

The antioxidant activity of the fortified maze-ogi fortified with ripe and unripe banana flours shown in Table 9 was determined using DPPH radical scavenging, metal chelating activity, and total phenolic content. For instance, Olagunju *et al.* (2022) investigated the fortification of wheat flour with baobab fruit powder and found an increase in DPPH radical scavenging activity and total phenolic content. Their findings align with the current study, where fortifying maize ogi with banana flour, particularly the unripe banana blend (UR80), significantly increased antioxidant activities. The unripe banana blend (UR80) exhibited the highest DPPH inhibition (38.96%) and metal chelating activity (38.47%), while the control sample (OGC) had the lowest. The total phenolic content of the fortified samples also increased, with UR80 showing the highest content (6.70 mg GAE/g), indicating that banana fortification significantly boosts the antioxidant properties of the product.

Table 8: Effect of Banana Addition on Colour of Maize Ogi

Sample	Form	L	a	b
OGC	Reconstituted	51.80	7.27	23.87
UB80	Reconstituted	62.02	2.07	10.20
RB80	Reconstituted	77.90	2.18	10.07
OGC	Dry	65.35	3.25	32.47
RBC	Dry	67.22	4.56	14.43
UBC	Dry	69.85	2.18	5.40
UB80	Dry	62.96	4.27	10.47
RB80	Dry	77.90	0.26	10.07

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Mineral content

The mineral content analysis of the fortification of maize-ogi with Ripe and Unripe banana flour samples shown in Table10 reveals significant variation across different formulations. The minerals measured include calcium (Ca), iron (Fe), potassium (K), and sodium (Na). The results indicate that banana fortification enhances the mineral profile of the maize ogi, particularly in terms of calcium and potassium content.

Table 9: Effect of Banana Addition on on Antioxidant of Maize Ogi flour

Sample	DPHH (%)	Metal Chelating (%)	Total Phenolic Content (mgGAE/100 g)
OGC	48.94±0.4196 [e]	31.89±0.5508 [a]	12.4±0.0500 [d]
RBC	28.51±0.5774[a]	45.46±0.4555 [d]	3.81±0.0252 [a]
RB80	31.76±0.3253 [b]	37.51±0.4368 [c]	4.26±0.0351 [b]
URC	36.76±0.1815[c]	49.54±0.2967 [d]	6.42±0.2228 [c]
UR80	38.96±0.0529 [d]	38.47±0.0462 [c]	6.71±0.3167 [c]

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Calcium (Ca) was highest in the URC (Unripe Banana Control) sample at 93.55 mg/100g, while the lowest was in the OGC (Control Ogi) sample at 17.66 mg/100g. This substantial increase in calcium content with unripe banana fortification suggests that unripe bananas are rich in calcium, contributing positively to bone health and overall nutritional value.

Iron (Fe) content ranged from 1.29 mg/100g in the OGC sample to 3.86 mg/100g in the RBC (Ripe Banana Control) sample. The higher iron content in the ripe banana-fortified samples indicates that banana fortification, especially with ripe bananas, can help address iron deficiencies in populations at risk of anemia.

Potassium (K) showed a notable increase with unripe banana fortification, reaching 254.46 mg/100g in the URC sample, compared to 58.4 mg/100g in the OGC sample. Potassium is essential for maintaining electrolyte balance and muscle function, making the fortified products suitable for elderly and infant populations.

Sodium (Na) content remained relatively low across all samples, with the OGC sample having the highest sodium content of 8.67 mg/100g. Fortification with bananas did not significantly increase sodium levels, making the fortified ogi a suitable option for low-sodium diets. The findings align with those of Akinyele and Oladeji (2019), who found that potassium-rich banana fortification in maize-based products improved the mineral intake among target groups.

Table 10: Effect of Banana Addition on Mineral Content of Maize ogi Flour

Sample	Ca (mg/100g)	K2(mg/100g)	Fe(mg/100g)	Na(mg/100g))
OGC	17.66±0.02517[a]	58.40±0.06658 [a]	1.29±0.02000 [a]	8.67±0.21362 [a]
RBC	74.45±0.14224 [b]	213.52±0.39577 [b]	3.86±0.07000 [b]	3.44±0.02082 [a]
RB80	54.48±0.31390 [c]	193.62±0.20817 [c]	3.37±0.04509 [c]	3.52±0.03512 [b]
URC	93.55±0.09504 [d]	254.46±0.43466 [d]	1.80±0.03215 [d]	4.18±0.03512 [b]
UR80	61.30±0.06083 [e]	190.46±1.85338 [e]	1.80±0.01155 [d]	4.39±0.04726 [c]

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Table 11: Effect of Banana Addition on Pasting Properties of Maize Ogi

Sample	Peak viscosities (RVU)	Trough (RVU)	Breakdown ((RVU)	Final Viscosity ((RVU)	Peak time (Minutes)	Pasting temperature ((°C)	Set back (RVU)
OGC	153.73 ± 1.06[a]	155.86 ± 0.16[a]	52.67 ± 0.17[a]	161.31 ± 0.13[a]	5.44 ± 0.03[c]	73.64 ± 0.16[a]	52.98 ± 0.26[a]
RBC	185.22 ± 1.08[d]	182.42 ± 0.32[e]	96.47 ± 0.80[d]	187.56 ± 0.32[e]	5.15 ± 0.03[a]	80.50 ± 0.12[c]	85.94 ± 0.99[d]
RB80	174.57 ± 0.25[b]	162.39 ± 0.31[b]	83.53 ± 0.29[b]	167.66 ± 0.34[b]	5.26 ± 0.03[b]	80.20 ± 0.10[b]	78.86 ± 0.08[b]
URC	194.76 ± 0.06[e]	178.29 ± 0.21[d]	96.86 ± 0.22[d]	183.66 ± 0.20[d]	5.37 ± 0.03[c]	80.86 ± 0.06[d]	81.44 ± 0.18[c]
UR80	181.27 ± 0.05[c]	166.11 ± 0.26[c]	87.63 ± 0.68[c]	171.54 ± 0.29[c]	5.43 ± 0.04[c]	80.32 ± 0.05[bc]	78.49 ± 0.43[b]

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; UR80: 80% Ogi: 20% Unripe Banana UBC: Unripe Banana Control

Table 12: Effect of Banana Addition on Proximate Composition of Maize Ogi

Sample	Appearance	Colour	Texture	Flavour	Taste	Overall Acceptability
OGC	7.85 ± 0.81 [c]	7.9 ± 1.21[b]	7.25± 1.16 [b]	7.3 ± 1.13 [a]	7.3 ± 1.17 [b]	7.75±0.91 [b]
RB80	5.95±1.39 [a]	6.0±1.52 [a]	6.55±1.19 [ab]	6.7 ± 1.56 [a]	6.85±1.50 [a]	6.55 ± 1.32 [ab]
UR80	6.95±1.12 [bc]	6.85±0.86 [bc]	7.3±1.53 [b]	6.7 ± 1.08 [a]	7.1 ± 1.23 [ab]	7.05 ± 1.23 [ab]
RB90	5.35±1.15 [bc]	5.25±1.50 [bc]	5.05±1.03 [b]	5.8 ± 1.36 [a]	5.9 ± 1.48 [ab]	5.4 ± 1.10 [ab]
UR90	5.75±0.81 [bc]	5.0±1.21 [c]	5.85± 1.53 [b]	5.6 ± 1.27 [a]	5.0 ± 1.50 [ab]	5.8 ± 1.23 [ab]

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; URC: Unripe Banana Control; UR80: 80% Ogi: 20% Unripe Banana.

Table 13 Effect of Banana Addition on Sensory Evaluation of Maize Ogi

Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fiber (%)	Carbohydrate (%)
OGC	8.61± 0.02 ^{b}	10.29 ± 0.10 ^{a}	2.38 ± 0.01 ^{d}	1 .11 ± 0.02 ^{d}	2.25 ± 0.01 ^{c}	75.39 ± 0.03 ^{d}
RBC	8.25 ± 0.01 ^{c}	9.22 ± 0.08 ^{c}	2.79 ± 0.02 ^{b}	1.98 ± 0.03 ^{b}	2.78 ± 0.02 ^{a}	76.98 ± 0.04 ^{b}
RB80	8.28 ± 0.02 ^{c}	7.85 ± 0.07 ^{d}	3.02 ± 0.02 ^{a}	3.93 ± 0.01 ^{a}	2.55 ± 0.02 ^{b}	76.98± .0.03 ^{a}
URC	8.11 ± 0.01 ^{d}	7.63 ± 0.06 ^{e}	3.11 ± 0.03 ^{a}	2.15 ± 0.03 ^{c}	2.86 ± 0.02 ^{a}	77.56 ± 0.02 ^{b}
UR80	8.28 ± 0.03 ^{c}	8.44 ± 0.06 ^{b}	3.02 ± 0.01 ^{a}	1.93 ± 0.02 ^{b}	2.65 ± 0.02 ^{b}	76.92 ± 0.03 ^{b}

OGC: Ogi Control; RBC: Ripe Banana Control; RB80: 80% Ogi: 20% Ripe Banana; URC: Unripe Banana Control; UR80: 80% Ogi: 20% Unripe Banana.

Pasting Properties

The pasting properties of the samples shown in Table 11 showed significant variation. The unripe banana blend (UR80) exhibited the highest peak viscosity, indicating enhanced thickening properties, while the control (OGC) had the lowest. This suggests that banana fortification improves the starch functionality of ogi, resulting in better viscosity and gel formation during cooking. This finding is consistent with the study by Oluwalana *et al.* (2019), who fortified maize flour with banana and observed a significant increase in peak viscosity

Proximate Composition Determination

The proximate composition analysis shown in Table 12 revealed that the moisture content of the samples ranged from 7.5% to 8.9%, with the unripe banana blend (UR80) showing the highest moisture retention. Protein content ranged from 8.2% to 10.1%, with fortified samples showing slight improvements. Crude fat content ranged from 3.1% to 4.5%, and carbohydrate content from 68% to 72%, with UR80 having the highest carbohydrate content. The mineral content (calcium, iron, potassium, sodium) was also enhanced, particularly in the UR80 sample. The elevated mineral content in fortified samples highlights the potential of banana fortification in improving the nutritional quality of maize ogi, aligning with findings by Adeyemi and Idowu (2012), demonstrated that banana fortification of maize-based products increased essential mineral concentrations.

Sensory Evaluation

The traditional maize ogi (OGC) shown in Table 13 received the highest sensory scores across all attributes, with overall acceptability at 7.75. The unripe banana-fortified sample (UR80) was rated higher in texture (7.00) and overall acceptability (7.00) compared to the ripe banana-fortified samples. The RB80 sample, with ripe bananas, scored lower in appearance (5.95) and overall acceptability (6.55), likely due to the softer texture and altered flavour. The UR90 sample, containing 10% unripe banana, achieved scores close to the control, indicating a favourable consumer response. (Iwe, 2010).

Conclusion

The fortification of maize ogi with ripe and unripe bananas enhanced its nutritional and sensory properties. The chemical analysis showed increased moisture and minor changes in fat, ash, and fibre content, with significant improvements in antioxidant properties ($p < 0.05$). Unripe banana fortification notably increased viscosity and starch stability ($p < 0.05$), enhancing the texture and acceptability of the product. Functional properties like bulk density, oil absorption, and swelling capacity were positively impacted by banana fortification, showing significant differences ($p < 0.05$) from the control. Sensory evaluation favoured the control sample (OGC) overall, while UR80, fortified with unripe bananas, was highly rated for texture and taste. In contrast, the RB80 sample, with less ripe bananas, was the least preferred.

Reconstituted ogi samples, tested with varying water volumes, showed minimal pH changes, maintaining overall acidity close to the dry flour. This suggests that reconstitution did not significantly ($P<0$) affect the product's chemical integrity, with only slight variations in pH observed at higher water volumes.

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A Review on the Nutritional Properties and Industrial Uses of Plantain and its byproducts (*Musa paradisiaca*)

[1]Oluwatola, J. O., [1]Awodiya, C. B., [1]Oduwaiye, C. E., [1]Abisoye, O. J., [1]Ogunlana, O. O., [2]Ayorinde, T. A. and [1]Malomo, A. A

[1]*Department of Food Science and Technology, Obafemi Awolowo University, Ile-Ife, Nigeria*
[2]*National Biotechnology Research and Development Agency*

Corresponding author: Oluwatola, J. O; Email: oluwatolajoshua@gmail.com

Abstract

Plantain is a perennial crop that is widely cultivated in tropical regions. It is playing an important role in ensuring food security and has found vast industrial applications across sub-Saharan Africa. Being a staple food crop, plantain is highly nutritious, containing dietary fibre, phenolic compounds, and minerals like Potassium and Phosphorus. This review delves into the nutritional profile of plantain, emphasizes its versatility in various culinary forms such as boiled, fried, and processed products like flour. It additionally explores the broader potential of plantain in non-food industries. Plantain peels and pseudostems, which are regarded as waste, have shown promising applications in bioenergy production, biodegradable packaging, and textile manufacturing, contributing to circular economies and environmental sustainability. This article also examines the variations in plantain at different stages of ripeness, which influence both nutritional content and industrial viability. By commingling recent research, this article highlights the significance of plantain as a sustainable resource with great potential for both food and non-food applications, providing pathways by which food security can be enhanced and eco-friendly innovations supported.

Key words: plantain, waste, fertilizer, flour, nutrition

INTRODUCTION

Plantain (*Musa paradisiaca*) is a member of the Musaceae family, specifically the genus *Musa* and a perennial crop that thrives in a variety of conditions (Nelson *et al*., 2006). Characterized by large, overlapping leaf stalks, the plant has an average height range of 1.22 to 6.10 meters (Oladiji *et al*., 2010). Renowned for its versatility, plantain serves various local applications and produces bunches with larger individual fruits compared to bananas, though with fewer fruits per bunch. Commonly referred to as "cooking bananas," plantains hold significant cultural and economic value in many regions. According to Kayode *et al*., (2013) and Bhuiyan *et al*., (2020), plantain is a staple food that offers numerous nutritional benefits, being low in fat and sodium, and high in carotenoids, a precursor of vitamin A. It serves as an important source of energy and starch in sub-Saharan Africa (Adepoju *et al*., 2012). Additionally, Plantain is abundant in phenolic compounds, dietary fibre, essential minerals like potassium and phosphorus, and vitamins including A, B1, B2, B6, and C. (Ekesa *et al*., 2015; Passo Tsao *et al*., 2015; Anyasi *et al*., 2018; Amah *et al.*, 2019). The concentration of this nutrients and minerals depends on influencing factors such as cultivar type, postharvest maturation, growing environment, climate, and farming techniques. (Naczk et al., 2006; Bennett *et al*., 2010; Pereira and Maraschin, 2015).

1.2 Global Importance and Utilization of Plantains

Plantains are vital staple crop, with approximately 60% of the world's plantain producted in Africa, majorly in the Central African region (42%) and West African region (40%) (FAOSTAT, 2021). The Democratic Republic of the Congo and Cameroon are the leading producers in Central Africa, while Nigeria and Ghana lead the production in West Africa. (Udomkun *et al*., 2021).

Consumed in various forms, plantains are commonly fried, boiled, roasted, or prepared as thin or thick porridge. They can also be processed into flour, which is often used to make composite flours, for confectionery and baking (Malomo *et al*., 2023). According to Nelson *et al*., (2006) and Phillip *et al*., (2009), plantains are the fourth most significant food crop in the world, behind rice, wheat, and maize, and are used in producing fermentable sugars, medications, beverages, and food flavorings.

Plantain offer significant nutritional and functional value regardless of the degree of ripeness. Ripe plantains are a primary source of carbohydrate and calories for over 70 million people in sub-Saharan Africa, providing 25% of daily carbohydrates and 10% of caloric intake. While unripe plantains have hypoglycemic properties and are used in the managing of diabetic complications (Egbebi, 2011; Adegunwa *et al*., 2019; Ayinde *et al*., 2017). Additionally, ripe plantains play a crucial role in enhancing food security in the region.

Objective and Scope of this Review

This review paper provides an analysis of the multifaceted applications, benefits, and advancements in plantain cultivation, utilization, and innovation. It focuses on the scientific, technological, nutritional, and environmental aspects of plantain and its derivatives, including food and non-food products, with an emphasis on sustainability.

CULTIVATION OF PLANTAIN

Overview of Plantain Cultivation Methods

There are at least 116 cultivars of plantain that have been identified in West and Central Africa. Plantains require a hot and humid environment to grow with an ideal average air temperature of 30ºC and rainfall of at least 100mm per month. The dry season spells should be short as irrigation is neither suitable nor economically viable for subsistent farmers but it may become necessary for large plantations. The method of propagation of plantain is by suckers. Harvesting is done after 3 to 4 months when 1 or 2 fingertips of the first-hand start yellowing. The bunch usually ripens within a week (IITA, 1990).

Maturity Stages

Maturity at harvest is one of the most important factors that determines postharvest-life and final quality such as appearance, texture, flavour, nutritive value of fruits and vegetables. Different characteristics (internal and external can be used to determine the maturity of plantain, and they include the diameter of the fruit, the age of the bunch, the angularity of the fruit, the length of the fruit and peel colour (NFCL, 2003). Ripening results in changes to the physical, chemical and mechanical properties of plantain. Some of these changes include the change in colour from green to yellow, a decrease in firmness and conversion of starch in the pulp to sugar (Tapre and Jain, 2012). Tapre and Jain (2012) also reported that there are seven stages in the maturation of plantain:

Stage 1 – All green
Stage 2 – Green with a trace of yellow
Stage 3 – More green than yellow
Stage 4 – More yellow than green
Stage 5 – Yellow with a trace of green
Stage 6 – All yellow
Stage 7 – All yellow with brown speckles

Nutritional and Mineral Composition of Plantain

In a study conducted by Adepoju *et al.*, (2012), plantain was found to contain high energy levels (148.6 kCal in 100g) in the raw form. It also contains high moisture and carbohydrate levels of 59.4g and 24.4g/100g respectively. Table 1 contains the nutritional information of various forms of plantain.

The mineral composition of these plantain forms is presented in table 2. Plantain is very high in Potassium, Sodium and Phosphorus.

Food and Non-Food Products Derived from Plantain

Food Products Derived from Plantain

Plantain, a staple food crop in many tropical countries, is very versatile. Its versatility allows it to be eaten in various forms, both processed and unprocessed. It can be consumed alone or in

Table 1: Proximate Composition of *Musa paradisiaca* (g/100g)

Sample	Raw	Sundried	Fermented	Boiled	Roasted Plantain
Moisture	59.4 ± 0.02	11.1 ± 0.03	11.2 ± 0.02	62.6 ± 0.03	47.3 ± 1.10
Crude Protein	7.7 ± 0.13	16.9 ± 0.12	3.4 ± 0.16	7.5 ± 0.09	3.3 ± 0.10
Crude Lipid	1.5 ± 0.02	3.9 ± 0.03	1.7 ± 0.01	3.8 ± 0.02	1.0 ± 0.02
Ash	1.4 ± 0.02	1.5 ± 0.01	0.8 ± 0.02	1.3 ± 0.02	2.4 ± 0.03
Crude Fiber	1.4 ± 0.02	3.8 ± 0.03	2.5 ± 0.02	1.5 ± 0.01	1.3 ± 0.02
Carbohydrates	24.4 ± 0.19	60.2 ± 0.11	78.5 ± 0.15	18.8 ± 0.11	44.8 ± 1.19
Gross Energy (kcal)	148.6 ± 0.14	350.5 ± 0.28	350.9 ± 0.14	144.4 ± 0.22	169.0 ± 1.00

Source: Adepoju et al (2012)

Table 2: Mineral Composition of *Musa parasidiaca* (mg/100g edible portion)

Sample	Raw	Sundried	Fermented	Boiled	Roasted Plantain
Sodium	200.0 ± 1.41	245.0 ± 21.21	85.5 ± 2.12	195.0 ± 21.21	55.7 ± 1.15
Potassium	370.0 ± 14.41	380.0 ± 21.21	160.0 ± 14.14	365.0 ± 14.14	270.0 ± 1.00
Calcium	126.5 ± 2.12	140.0 ± 3.50	77.5 ± 2.12	93.0 ± 2.83	160.0 ± 10.00
Magnesium	375.0 ± 21.21	405.0 ± 15.36	195.2 ± 12.21	340.0 ± 14.14	350.0 ± 13.61
Iron	2.53 ± 0.03	3.50 ± 0.02	1.38 ± 0.02	2.45 ± 0.04	3.48 ± 0.01
Phosphorus	220.0 ± 21.21	225.0 ± 17.43	165.0 ± 11.21	190.0 ± 14.14	217.0 ± 11.16
Zinc	3.74 ± 0.02	3.66 ± 0.02	3.13 ± 0.01	3.60 ± 0.02	3.70 ± 0.02
Manganese	2.99 ± 0.05	2.74 ± 0.03	2.47 ± 0.02	2.65 ± 0.03	2.80 ± 0.02
Copper	1.66 ± 0.04	1.74 ± 0.02	1.47 ± 0.02	2.20 ± 0.02	1.60 ± 0.01

Source: Adepoju *et al*. (2012).

combination with other foods, which makes it applicable for consumption as an appetizer, a whole meal, a side dish or dessert. Some common products commonly produced from plantain include: boiled plantain, fried plantain (*dodo*), *boli* (Roasted plantain), plantain chips, peel or fruit pulp (swallow) and plantain wine.

dodo Ikire, croquettes, cosettes, flours (sweetened and unsweetened) from both the ripe and unripe pulps, weaning foods, braised plantain, plantain porridge, dried ripe pulp, jam, plantain leather, gelatinized purée either from

Plantain Peel Flour

Plantain peel is often discarded as waste in various countries around the world is indeed a very valuable and highly nutritious component of the plantain fruit that can be employed in the production of both food and non-food products, basically for the vast health benefits it provides. The use of plantain peels has been adopted in various cultures, primarily in Africa, Latin America, and some parts of Asia. It is commonly used in the preparation of dishes owing to the added fibre and nutrients it supplies. Plantain peels are rich in essential nutrients and phytochemicals, making them a valuable resource for both animal and human consumption. The peels contain significant amounts of crude protein, fiber, and minerals such as potassium, calcium, and magnesium. Phytochemical analyses have revealed the presence of saponins, cardiac glycosides, tannins, terpenoids, and flavonoids, which contribute to their nutritional and medicinal properties (Arogbodo et al. 2021). Recently, flour prepared from maturated plantain peels was used as a source of antioxidant dietary fibre to prepare cookies (Arun et al., 2015).

The final product that can be obtained from plantain peel depends on its chemical composition which is greatly influenced by its stage of ripening. Peel from unripe plantain fruit presents (on a dry basis) 6–10% protein, 6–12% ash, 2–6% lipids, 11–39% starch, and 33–43% total dietary fiber (TDF); from the TDF, around 5–13% is soluble dietary fiber (SDF) and 7–36% is insoluble dietary fiber (IDF) (Happi-Emaga et al., 2008). Pectin and gums (xanthan, arabic, guar, etc.) are present in the SDF, whereas cellulose, hemicelluloses, and lignin are included in the IDF. Nutritionally, the type, level, and structure of the components in the SDF and IDF, as well as the ratio of both fractions play and important role in the physiological properties in the human body after consumption (Champ et al., 2003).

The processing of plantain peel into flour involves cleaning and drying the peels thoroughly to remove any dirt and moisture. The dried peels are then ground into a fine powder using a grinder or food processor. The plantain peel flour obtained is then sifted to ensure a uniform texture and is then packaged for use in various recipes or as a nutritional supplement. The peel processed into flour is used in production of baked products due to its nutritional and health benefits as well as its sustainability, it also improves the texture, flavour and moisture content of the baked products.

Boiled Plantain

Boiled plantains are typically prepared by peeling the fruit or not and boiling it in water until tender. Depending on the variety and ripeness of the plantain, the cooking time can vary. Green (unripe) plantains are often starchy and firm, while ripe plantains become sweeter and softer when boiled. In some cultures, plantains are boiled with a pinch of salt or other spices to enhance flavor. In west African countries like Nigeria and Ghana, boiled plantain is commonly eaten with accompaniments such as stews, soups, or sauces. It may also be served with beans or groundnut sauce. In the Caribbean, particularly in countries like Jamaica and the Dominican Republic, boiled plantain is a part of the traditional breakfast and is also often consumed as a side dish with fish, meat, or stews. In countries like Colombia and Venezuela, boiled plantains are also frequently served with meat dishes or as part of the traditional "Pabellón Criollo" (Venezuela's national dish). In Asian regions such as the Philippines, boiled plantains are often eaten with sugar or used in desserts, though they are also served as a side dish (Davidson, 2014; Ortiz Cuadra, 2013).

Boiled plantains are a rich source of complex carbohydrates, providing energy and dietary fiber. They are also a good source of vitamins A, C, and B6, as well as potassium, magnesium, and iron. The nutritional profile varies depending on the ripeness of the plantain; unripe plantains are higher in starch, while ripe plantains contain more sugars (Davidson, 2014).

Fried Plantain

Fried plantains are prepared by peeling ripe or unripe plantains, slicing them into rounds or diagonal pieces, and frying them in hot oil until golden brown. The ripeness of the plantain influences its taste: ripe plantains yield a sweet flavor, while unripe ones are starchier and savorier. The frying process can vary slightly by region, with some adding a pinch of salt or spices before frying.

In West Africa, fried plantains, known as dodo in Nigeria and Ghana, are a common accompaniment to meals, often served with rice, beans, or rich stews. They are also enjoyed as a snack on their own. In the Caribbean, particularly in Jamaica and Cuba, fried plantains are a popular side dish, often paired with jerk chicken, rice, and peas, or included in traditional breakfasts. In Latin America, fried plantains, known as plátanos maduros fritos in Colombia and Venezuela, are a staple side dish, often served alongside main dishes like Pabellón Criollo or enjoyed with cheese. In the Philippines, fried plantains are sometimes prepared as turon, where they are wrapped in a spring roll wrapper, coated with sugar, and served as a sweet dessert.

Nutritionally, fried plantains are a rich source of carbohydrates, making them a significant source of energy. They also provide essential vitamins such as A and C, as well as potassium and dietary fiber. However, due to the frying process, they are higher in fat and calories compared to boiled or baked plantains. The nutritional content can also vary depending on the ripeness of the plantain and the method used for frying (Ortiz Cuadra, 2013).

Dodo Ikire

Dodo Ikire is a cherished traditional snack originating from the town of Ikire in Osun State, Nigeria. The word is literally translated to *dodo* (plantain) from Ikire (a town in Osun State, Nigeria). Unlike the typical fried plantains found across the region, *dodo Ikire* is made using overripe plantains, which contribute to its distinct flavor and texture. This unique delicacy has deep roots in Yoruba culture and has become popular throughout southwestern Nigeria.

The preparation of *dodo Ikire* starts with mashing overripe plantains into a thick paste. This paste is then mixed with a small amount of salt, pepper, and sometimes palm oil, creating a flavorful blend that's both sweet and spicy. The mixture is shaped into small, rounded balls or oblong patties, which are then deep-fried in hot oil until they develop a dark brown, almost black, crispy exterior. The result is a snack with a rich, caramelized flavor that is slightly chewy on the inside and crispy on the outside (Kayode *et al.*,2013).

Dodo Ikire is often enjoyed as a snack or side dish at any time of the day. It is commonly sold by street vendors and in local markets, where it is typically wrapped in leaves or paper. The snack is beloved not only for its unique taste but also for its long shelf life, making it a convenient option for travelers and a nostalgic treat for those who grew up in the region.

Nutritionally, *dodo Ikire* is rich in carbohydrates, providing a quick source of energy. It also contains dietary fibre, vitamins A and C, and potassium. However, due to the deep-frying process, it is relatively high in fat and calories. The addition of pepper also provides some antioxidant benefits, contributing to its overall nutritional value (Kayode *et al.*,2013).

Beyond its nutritional aspects, *dodo Ikire* holds significant cultural importance. It is more than just a snack; it symbolizes the heritage of the people of Ikire. The recipe has been passed down through generations, and the snack is often associated with local festivals and communal gatherings (Kayode *et al.*,2013). Its distinctive preparation and unique taste have made it a beloved treat across Nigeria, especially in Osun State.

Plantain Croquettes

Plantain croquettes are a delicious variation of the traditional croquette, offering a unique blend of sweet and savory flavors. These croquettes have their roots in Latin American and Caribbean cuisine, where plantains are a staple ingredient (Ottis Cuadra, 2013). The use of plantains in croquettes adds a distinctive flavor and texture that sets them apart from the more common potato or meat-filled varieties (Berrios and Morales, 2007).

To prepare plantain croquettes, ripe plantains are typically boiled or steamed until they are soft enough to be mashed into a smooth consistency. This mashed plantain mixture forms the base of the croquette. The filling can vary depending on regional preferences, but common fillings include seasoned ground meat, cheese, or a combination of vegetables and spices (Albala, 2011). Once the filling is added, the plantain mixture is shaped into small cylinders or balls.

The croquettes are then coated in breadcrumbs, sometimes after being dipped in beaten egg to help the breadcrumbs adhere. They are fried until golden brown, resulting in a crispy exterior that contrasts beautifully with the soft, sweet, and savory interior. The frying process not only gives the croquettes their characteristic crunch but also enhances the natural sweetness of the plantains (Davidson, 2014).

In Latin American and Caribbean countries, plantain croquettes are often served as a snack, appetizer, or side dish. In Puerto Rico, for instance, these croquettes, known as *alcapurrias*, are filled with seasoned meat and fried to perfection. In Cuba, they are often served alongside rice and beans or as a part of a larger meal. The versatility of plantain croquettes means they can be enjoyed on their own or paired with dipping sauces such as garlic aioli, salsa, or a spicy mayonnaise (Davidson, 2014).

Nutritionally, plantain croquettes are a good source of carbohydrates, primarily from the plantains, which provide energy and dietary fiber. They also contain vitamins A and C, potassium, and a moderate amount of protein, depending on the filling. However, as with other fried foods, they are higher in fat and calories, particularly due to the frying process (Berrios and Morales, 2007). Despite this, they are a satisfying and flavorful dish that can be enjoyed in moderation as part of a balanced diet.

Plantain croquettes represent a fusion of traditional croquette preparation with the rich flavors of plantains, offering a delightful twist on a beloved dish. Their sweet-savory combination makes them a popular choice in many households, and they continue to be a favorite at gatherings and celebrations (Ortiz Cuadra, 2013).

Flours (Sweetened and Unsweetened)

Plantain flour is a versatile and nutritious ingredient made from either ripe or unripe plantains, each with its own distinct culinary uses and health benefits. This flour is especially common in African, Caribbean, and Latin American cuisines, where plantains are a staple. The process of creating plantain flour involves drying and grinding the fruit, a method that has been used for generations to preserve plantains and extend their shelf life.

Ripe plantain flour is produced from fully matured, yellow plantains. The process begins by peeling the plantains and slicing them into thin pieces. These slices are then dried, either under the sun or in a dehydrator, until they are completely moisture-free. Once dried, the plantain pieces are ground into a fine powder, which is then sieved to achieve a smooth texture. Due to the higher sugar content in ripe plantains, this flour has a naturally sweet flavor, making it a great ingredient for baking and desserts (Mepba *et al.*, 2007).

On the other hand, unripe plantain flour is made from green plantains. The preparation method is similar: the green plantains are peeled, sliced, dried, and then ground into a fine powder. However, unripe plantain flour has a more neutral or slightly starchy flavor, which makes it ideal for savory dishes and as a gluten-free alternative to wheat flour in various recipes (Adebayo-Oyetoro *et al.*, 2017). The lower sugar content and higher starch levels in unripe plantains contribute to its different culinary applications.

The sweet taste of ripe plantain flour makes it perfect for use in baked goods like cakes, muffins, and pancakes. It can also be used to make porridges, puddings, and baby foods. In many African and Caribbean cultures, it serves as a natural sweetener in traditional dishes, and its rich flavor allows it to be a substitute for other flours in sweet recipes (Adebayo-Oyetoro *et al.*, 2017).

Unripe plantain flour, with its neutral flavor, is widely used in making staple foods like fufu, a dough-like dish that is central to many West African meals. It is also employed to thicken soups and stews or as a base for gluten-free bread and other baked goods. Due to its high resistant starch content, unripe plantain flour is valued for its potential health benefits, including improved digestion and better blood sugar management (Olawuni *et al.*,2018).

Nutritionally, both ripe and unripe plantain flours are rich in dietary fiber, potassium, and vitamins A and C. Unripe plantain flour is particularly noted for its low glycemic index, making it a healthier option for individuals managing diabetes or those looking to control their blood sugar levels. Although ripe plantain flour contains more sugars, it still offers significant nutritional benefits and serves as a good source of energy, especially for active individuals (Mepba *et al.*, 2007).

In summary, plantain flour, whether derived from ripe or unripe plantains, is a versatile and nutritious ingredient that plays an important role in various culinary traditions. Its wide range of applications and health benefits make it a valuable addition to both traditional and modern diets.

Plantain Fruit Leather

Plantain fruit leather is a delicious and nutritious snack made from ripe plantains and it is common in tropical countries where plantains are grown. It is a traditional fruit leather that leverages on the natural sweetness and texture of plantains. The process involves drying ripe plantains to create a chewy, flavorful snack that retains the fruit's essential nutrients.

The processing of plantain leather involves selecting ripe plantains, blanching them to preserve color and texture, the blanched plantain is then blended into puree consistency. The puree obtained is spread into thin layers and dehydrated to remove moisture, creating a leathery texture. After drying, the plantain leather is cut into pieces and packaged for distribution (Dimante *et al.*, 2014). Plantain fruit leather is rich in fiber, potassium, and vitamins, it offers a wholesome alternative to processed snacks. It is not only a great way to utilize excess plantains but also provides a convenient, portable, and healthy treat perfect for ready to eat snack.

***Agadagidi* (Plantain Wine)**

Agadagidi is a drink popular in the Southern part of Nigeria. It is made from overripe plantain which is fermented with wine yeast. It is produced by processing the pulp into juice (must) which is then fermented with *Saccharomyces cerevisiae* (wine yeast) for 72 hours and it will be filtered after (Omojasola *et al.*, 2012 and Malomo *et al.*, 2022).

Non-Food Products from Plantain

Plantain as a Bioenergy Source

Dependence on fossil fuel has led to several environmental challenges and climate change across the world, and this has made it a necessity to look at alternative renewable and ecofriendly energy sources (Giwa *et al.*, 2023). After harvest, a large amount of plantain plant parts and peels are wasted. Plantain biomass was reported by Odude *et al.* (2017) to be a good heterogenous solid catalyst (HSC) for the synthesis of biodiesel.

Paper

The use of non-wood fibers could provide a solution to the growing pulpwood costs and the projected future increase in fiber scarcity. Research has been focused on expanding the variety of non-wood plants in order to achieve this goal; the bulk of these species have already found commercial application (Ray *et al.*, 1990).

Prior to attaining fruiting maturity, plantains develop for six to seven months. At that point, the fruit is cut off, the aerial stem is felled, and the stem is allowed to rot. This occurs as a result of the sucker, a subterranean stem that generates new shoots and is how the plant spreads. A huge fleshy core is located in the center of the folds, and plantain pseudostems are soft, mushy structures that are actually the lower parts of the leaves folded together. Each fold contains structures with some intercellular holes. Lignin and hemicelluloses form the bonds that hold cellulosic filaments, which are the building blocks of the pseudostem, apart from the core (Akpabio *et al*., 2012). The pulping procedure separates the fibers that comprise the filaments. According to Akpabio *et al*., (2012) the filaments can be locally processed into strands for use in the production of textiles like garments and ropes

Ogunsile *et al*., (2008) state that samples are pulped in a 10-liter stainless-steel digester that is heated electrically as part of the pulping experiment. Weighing and charging the chips from the plantain pseudostem into the digester with the necessary amount of chemical solution at a liquor to solid ratio of 10:1. Throughout the experiment, the digester should be kept at the operational temperatures of 150°C and 170°C for durations of 30, 90, and 150 minutes. The final pulp is carefully cleaned with tap water, and after drying in the oven at 102°C to constant weight, the pulp yield will be calculated gravimetrically. The TAPPI standard describes how the pulps are evaluated for Kappa number. From the Kappa number, the Residual Klason Lignin (RKL) is calculated by multiplying with a factor of 0.13 (TAPPI, 1993).

Plantain in Textile

Plantain fibre is a good raw material for textile production because of its numerous properties. It is easy to access and can be available in sufficient quantity. It has long and strong fibre that can withstand the mechanical operation of twisting, braiding, and weaving, without breaking. Akubueze etal (2015) quoting Koziowski (1996) suggested that the demand for fibres used for clothing is expected to rise from the current 60 million tons to about 130 million tons per year by 2050. It further explained that "A plantain or banana plantation of about 500,000 acres might yield 100,000-200,000 tons of fibre and a fresh pseudo-stem yields about 1-5% of fibre.'' This confirms that plantain fibre can be processed as a suitable substitute for textile and other related products. One can then imagine the magnitude of valuable fibres that have been wasting in Nigeria due to non utilization. With the economic meltdown being experienced in Nigeria presently, this wastage must be harnessed to generate income for the nation.

Plantain fibres, derived from the pseudo stems of the plantain plant, are known for their strength and durability. These fibres are processed by harvesting the pseudo stems, stripping the fibres, and then retting and drying them before spinning into yarn and weaving into fabrics. They are valued for their tensile strength, durability, and moisture-wicking properties, making them useful for various textile applications. Traditionally used for ropes and mats, plantain fibers are now being explored for eco-friendly clothing and accessories due to their sustainability. This use of plantain fibers supports environmental goals by providing a biodegradable and renewable alternative to synthetic materials.

Cosmetics

A study by Lambrud *et al.*, (2024) on the formulation and evaluation of a herbal face wash enriched with plantain extract, renowned for its medicinal properties. The formulation process involved the selection of appropriate surfactants, humectants, and other additives to ensure stability and efficacy. Plantain extract was incorporated due to its antioxidant, anti-inflammatory, and antimicrobial properties, which are beneficial for skincare. The face wash was subjected to various tests, including pH, viscosity, stability, and microbiological analysis, to ensure its quality and safety. The results demonstrated that the herbal face wash containing plantain extract exhibited suitable physiochemical properties, stability, and antimicrobial efficacy, making it a promising natural alternative for skincare routines. Further studies are warranted to explore its long-term efficacy and potential applications in skincare formulations.

Advantages

1. Natural Cleansing: Plantain contains compounds that can gently cleanse the skin without stripping away its natural oils, making it suitable for various skin types, including sensitive skin.

2. Anti-inflammatory Properties: Plantain has anti-inflammatory properties that can help soothe irritation and redness, making it beneficial for those with acne or sensitive skin conditions.

3. Antioxidant Benefits: The antioxidants present in plantain can help protect the skin from damage caused by free radicals, promoting healthier and more youthful-looking skin.

4. Moisturizing: Some plantain face wash products may contain moisturizing ingredients that can help hydrate the skin, leaving it feeling soft and smooth.

5. Natural Exfoliation: Plantain may also possess mild exfoliating properties, helping

to remove dead skin cells and promote cell turnover for a brighter complexion.

Fertilizers

Plantain peels contain nutrients that are essential for healthy potted plants. However, these peels do not contain everything your plant needs. As they decompose, plantain peels add potassium as well as small amounts of nitrogen, phosphorus and magnesium to the soil in a similar fashion as a slow-release fertilizer. Most plants need a certain amount of these top three macronutrients: nitrogen, phosphorus, and potassium. Some plants are more needful of nitrogen, while others are more needful of phosphorus, and still others need a higher level of potassium.

Potassium helps your plants move water and nutrients between cells. It strengthens the stems of your plants and protects them from disease. It is used to help the flowering process and is thought to be able to improve the quality of the fruit of your plants. At 42% potassium, plantain peels are a fantastic source (Wallingford, 1980). The peels are one of the highest organic potassium sources, and even loads higher in potassium than wood ash. The peels do not contain much nitrogen. Plantain peels also contain calcium, which helps plants take up more nitrogen, which some potassium loving plants need. It also contains manganese, which helps with photosynthesis; sodium, which helps movement of water between cells; and magnesium and sulfur, both of which are helpful in the formation of chlorophyll.

A study by Nana (2020) showed sufficient yield and quality of tomatoes, compared to the conventionally grown ones, can be obtained by organic production system using appropriate combinations of organic and inorganic fertilizers such as the plantain peel and NPK fertilizer with no consequential effects of the various fertilizer treatments (plantain peel) on properties of tomato fruits. The adoption of plantain peel would significantly minimize challenges with disposal of organic waste within the urban and suburban area of the country, thereby reducing pollution in the environment, increases productivity and create employment opportunities when all these peels are recycled into proper usage.

The use of plantain peels as a source of nutrients holds potential for small scale greenhouse tomato production while minimizing environmental pollution. It also helps to improve soil texture, to retain water longer, and to increase microbial action in the soil. Chemical fertilizers, on the other hand, are very expensive and can cause soil degradation and environmental pollution if not used appropriately (Nana, 2020).

Biodegradable Packaging:

Plastics offers a variety of benefits, in a variety of shapes, such as sheets, panels, film which can all be flexible as the application requires. However, use of too many plastics results in massive harmful effects. It takes longer time to degrade which is estimated about 500 years to degrade and will become toxic after decomposed. With the ever-increasing demand of plastics in the world and their consequent disastrous effects on environment, a suitable environmentally friendly substitute like biodegradable plastics is presently in need. A study by Onyemata *et al*. (2023) which centers on the production of a variety of bioplastic samples from plantain and yam peels with varying amount of the filler and plasticizers. Glycerol and sorbitol have been utilized separately as the plasticizers to increase its flexibility.

The produced bioplastic shares the same characteristics to the work conducted by (Ezgi *et al.*, 2019). It shows that the produced bioplastic was non-porous and had a high-water retaining capacity. Some other notable characteristics were the light brown color of the bioplastic, its solid formation and smooth surface area. Various quantities and mixtures of plasticizers and fillers were used to create samples of each starch-based bioplastic. For all samples, the acetic acid concentration was maintained constant. (Onyemata *et al*., 2023).

Conclusion

This review would synthesize current research and innovations related to plantain, highlighting its significance as a multipurpose crop for food, industry, and sustainability. It would also identify knowledge gaps and propose future research directions to maximize the crop's potential for economic and environmental benefits.

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Banana and Plantain as Bio-resources for Building a Sustainable Circular Economy

Ajiboye, O. O., Oyewole F. B and Alakija, O. O

Food Science and Technology, Obafemi Awolowo University, Osun State, Nigeria

Corresponding author: ajiboyeoluwatobi03@gmail.com

ABSTRACT

Plantain belongs to the genus Musa of the family musaceae. Nearly all edible plantain cultivar are derived from two wild species, *M. acuminate* and *M. balbisiana* (Robinson, 1996). These wild species are classified based on the proportion of the genetic constitution contributed by each parental source (Robinson, 1996). Plantain (*Musa spp*.) is an important dietary source of carbohydrates in the humid tropical zones of Africa, Asia and South America. (Robinson, 1996). Plantain is rich in vitamins A, C and B group as well as minerals such as calcium and iron (Marriott & Lancaster, 1983). Musa spp. are useful as food to be consumed by humans either as flour to be used in confectionaries or as jams and jellies; in chips etc. Its peel can be used as animal feed. All parts of the banana plant have medicinal applications: the flower in bronchitis and dysentery and on ulcers, cooked flowers are given to diabetics etc. Its leaves are also useful for lining cooking pots and for wrapping. Improved processes have also made it possible to utilize banana fibre for ropes, table mats and handbags (Chandler, 1995).

Despite these many uses of *Musa spp*. and the huge tonnages harvested each year, there are certain problems such as inaccessibility to production areas, far distances between production areas and customers, inadequate infrastructures for harvesting, carelessness on the part of harvesters and handlers among others which are all factors that lead to high rate of postharvest losses, hence the need for processing of these important crops. Different processing methods of *Musa spp.* into new food products which include the production of flour, preparation of jams and jellies and the quality attributes of the products obtained from processed Musa spp. were reviewed. It can, therefore, be concluded that subjecting Musa spp. to processing methods will help enhance and improve the value of the fruit and make it available all year round for better utilization.

INTRODUCTION

Bananas and plantains are versatile and economically important crops that play a vital role in the livelihoods of millions of people, particularly in the tropical and subtropical regions of the world (Faturoti et al., 2007). These crops not only provide a rich source of nutrients and calories, but their by-products and waste can also be harnessed as valuable bio-resources to promote a sustainable circular economy.

Beyond their importance as a food source, these crops present significant potential as bio-resources for building a sustainable circular economy (Faturoti et al., 2007). Banana floral stalks and peels, which make up a significant portion of the total plant mass, are often underutilized and considered waste. These by-products can be repurposed and transformed into value-added products, contributing to the development of a circular economy.

Research has shown that banana and plantain by-products can be used in the production of bioplastics, packaging materials, animal feed, bio-fertilizers, and even biofuels (Padam et al., 2012). Additionally, the bioactive compounds found in banana peels can be extracted and used in various industries, such as pharmaceuticals, cosmetics, and food processing. (Pathak et al., 2016)

RESOURCES AND BIO-RESOURCES OF PLANTAIN AND BANANA

The bulk of the banana, cooking banana and plantain are eaten either as raw, in the ripe state, or as a cooked vegetable, and only a very small proportion are processed in order to obtain a storable product. Generally, preserved products do not contribute significantly to the diet of the millions of people who eat banana, cooking banana and plantain, however in some countries or areas, the processed or preserved products are important in periods when food is scarce. Processing is

recognized as a way of preserving the fruit. Yet the proportion of fruits processed and the suitability of the various Musa groups to processing is relatively unknown. New Musa hybrids should therefore be screened for their processing quality or suitability for processing (Thompson, 1995).

1) **Banana puree** is important as infant food and can be successfully canned by the addition of ascorbic acid to prevent discoloration. The puree is produces on a commercial scale in factories close to banana fields and packed in plastic-lined 10 cans and 55-gallon metal drums for use in baby foods, cake, pie, ice cream, cheesecake, doughnuts, milk shakes and many other products (Ogazi, 1996).

2) **Banana or plantain flour, or powder**, is made domestically by sun drying slices of unripe fruits and pulverizing (Anon, 1999). Commercially, it is produced by spray-drying, or drum-drying, the mashed fruits (Anon, 1999). Flour can be made from green unripe banana, cooking banana or plantain. Fruits are hand-

peeled and sliced or chopped into pieces about 5-10 mm thick. The slices will be dried in the sun by spreading out the slices on mats, on bamboo framework, on cement floors, or on a roof or sheets of corrugated iron or simply on a sweptbare ground. Various designs of solar dryers can also be used, or they may be dried in ovens, over fires, in a cabinet dryer or tunnel dryer (Thompson, 1995). The fruits are either sun-dried which is the former, oven-dried, the latter or foam-mat dried which will be described now. Sun and oven-drying methods have been used for drying of plantain and banana (Bowrey et al., 1980; Johnson et al., 1998; Demirel & Turhan, 2003) with some success, the introduction of foam-mat drying brought much more (Falade and Olugbuyi, 2009). Musa spp. especially cooking banana is cheaper relatively when compared with wheat and other cereals for the production of flours therefore processing of cooking banana should be encouraged. The flour can be mixed 50-50 with wheat flour for making cupcakes. Two popular Puerto Rican foods are "pasteless" and "alcapurais" both are pastry stuffed with meat, the first is wrapped in plantain leaves and boiled the latter is fried. The pastry is made of plantain flour or a mixture of plantain with cassava or cocoyam.

Moisture removal from plantain seems to be an appropriate and economical means of preserving Musa spp, resulting in shelf stable and convenience products. Currently, unripe plantain flour is being processed into a thick paste product known as 'amala' in the western part of Nigeria, which is medically recommended for diabetic patient (Adeniji et al., 2006). Ripe banana powder is used in bakery and confectionery industries, in infant diets and the treatment of intestinal disorders (Adeniji et al., 2006).

3) Canned slices

Several methods for canning banana slices in syrup have been described (Thompson, 1995). Best quality slices are obtainable from fruit at an early stage of ripeness. The slices are processed in syrup of 25° Brix with pH of about 4.2 and in some processes calcium chloride (0.2%) or calcium lactate (0.5%) are added as firming agent (Marriot and Lancaster, 1983). Canning plantain slices in syrup are considered to be unsatisfactory (Sanchez-Nieva and Hernandez, 1967). However, ripe slices may be cooked in 40° Brix syrup until the concentration of the syrup reaches 54-60° Brix and cinnamon and lemon juice is added to improve the colour. The product may be packed in boilable plastic pouches and quickly frozen at -23°C. It is served by boiling the pouches in water for 15mins.

4) Chips (Crisps)

Various methods of preparing banana or plantain chips have been described in the literature. Typically, unripe bananas or plantain may be thinly sliced vertically or transversely (1.2-0.8 mm thick) (Berg et al., 1971). The slices are immersed in a sodium or potassium metabisulphate solution (to improve the colour of the final product or to prevent discolouration) and fried in hydrogenated oil at 180-200°C. The fried slices are dusted with salt and antioxidant (e.g. butylatedhydroxytoluene to delay rancidity); (Marriot and Lancaster, 1983). Alternatively slices may be dried before frying and the antioxidant and salt are added with the oil. Fried chips should have moisture content of about 1.5 to 2.0%. The temperature at which the chips are fried and the frying time affects their oil content, appearance, texture and flavour (Thompson, 1995). The chips must be packed in moisture-proof bags to prevent them from absorbing moisture and losing their crispness.

5) Jam and Jelly

The various methods of preparing jam and jelly have been described in several literatures. In one method for the preparation of jelly, fully ripe or over-ripe fruits are used. Fruits are hand-peeled and cut into 2 cm pieces or slices. The slices are boiled for 1hr in 60° Brix sugar syrup at the rate of 1lb of banana to 1 pint of syrup (454 g to 0.5681). This is then strained and the clear solution is boiled until it sets. The pH should be adjusted to 3.5. Pectin may be added to improve the set (Thompson, 1995). A commercial formula for producing banana jam is as follows (Thompson, 1995): 200lbs of sugar, 10 gallons of water and 12 ounces of cream of tartar. These are heated to 110°C and then 2.5 gallons of lemon juice (lime juice or citric acid can be used to replace the lemon juice to reduce the pH of the jam to 3.5) are added. The mixture is heated to 107°C until the correct consistency is obtained.

6) Medical uses

All parts of the banana plant have medicinal applications: the flowers in bronchitis and dysentery and on ulcers; cooked flowers are given to diabetics; the astringent plant sap in cases of hysteria, epilepsy, leprosy, fevers, hemorrhages, acute dysentery and diarrhea, and it is applied on hemorrhoids, insect and other stings and bites, young leaves are placed as poultices on burns and other skin afflictions, the astringent ashes of the unripe peel and of the leaves are taken in dysentery and diarrhea and used for treating malignant ulcers, the roots are administered in digestive disorders, dysentery and other ailments; banana seed mucilage is given in cases of catarrh and diarrhea in India (Anon, 1999).

Antifungal and antibiotic principles are found in the peel and pulp of fully ripe bananas. The antibiotic acts against Mycobacteria. A fungicide in the peel and pulp of green fruits is active against a fungus disease of tomato plants. Norepinephrine, dopamine and serotonin are also present in the ripe peel and pulp. The first two elevate blood pressure; serotonin inhibits gastric secretion and stimulates the smooth muscle of the intestines (Anon, 1999).

7) Animal Feed

Rejected ripe bananas, supplemented with protein, vitamins and minerals, and are commonly fed to swine. Green bananas are also used for fattening hogs but, because of the dryness and astringency and bitter taste due to the tannin content, these animals do not care for them unless they are cooked, which makes the feeling costs too high for most growers. Therefore, dehydrated green banana meal has been developed and, though not equal to grain, can constitute up to 75% of the normal hog diet, 40% of the diet of gestating sows. It is not recommended for lactating sows, nor is ripe bananas even with a 40% protein

supplement (Anon, 1999). Beef cattle are very fond of green bananas whether they are whole, chopped or sliced. Because of the fruit's deficiency in protein, urea is used at the rate of 8.8lbs (4 kg) per ton, with a little molasses mixed in to mask the flavor. But transportation is expensive unless the cattle ranch is located near the banana fields. A minor disadvantage is that the bananas are somewhat laxative and the cattle need to be washed down daily. With dairy cattle, it is recommended that bananas constitute no more than 20% of the feed (Chandler, 1995).

In the Philippines, it has been found that meal made from dehydrated reject bananas can form 14% of total broiler rations without adverse effects. Meal made from green and ripe plantain peels has been experimentally fed to chicks in Nigeria. Flour from unpeeled plantains, developed for human consumption, was fed to chicks in a mixture of 2/3 flour and 1/3 commercial chick feed and the birds were maintained until they reached the size of fryers. They were found thinner and lighter than those on 100% chick feed and the gizzard lining peeled in shreds. It was assumed that these effects were the result of protein deficiency in the plantains, but they were more likely the result of the tannin content of the flour which interferes with the utilization of protein (Anon, 1999).

Leaves, pseudostems, fruit stalks and peels after chopping, fermentation and drying, yield a meal somewhat more nutritious than alfalfa press cake. This waste material has been considered for use as organic fertilizer in Somalia. In Malaya, pigs fed the pseudostems are less prone to liver and kidney parasites than those on other diets.

Banana peel contains beta sitosterol, stigmasterol, campesterol, cyclocucalenol, cycloartanol and 24-methylene cycloartanol (Anon, 1999). The major constituents of banana peel are 24-methylene cuycloartanol palmitate and an unidentified triterpene ketone (Anon, 1999)

8) Other Uses

Bananas and plantain leaves are widely used as plates for lining cooking pits and for wrapping food for cooking or storage. A section of leaf often serves as an eye shade (Anon, 1999). In Latin America, it is a common practice during rains to hold plantain leaf by the petiole, upside-down, over one's back as an "umbrella" or "raincoat" (Anon, 1999). The leaves of the 'Fehi" banana are used for thatching, packing and cigarette wrappers. The pseudomonas has been fastened together as rafts. Seat ads for benches are made of strips of dried banana pseudostems in Ecuador. In West Africa, fiber from the pseudostem is values for fishing lines. In the Philippines, it is woven into a thin, transparent fabric called "agna" which is the principal material in some regions for women's blouses and men's shirts. It is also used for making handkerchiefs. In Ceylon, it is fashioned into soles for inexpensive shoes and used for floor coverings (Thompson, 1995).

Plantain fibre is said to be superior to that from bananas. In the mid-19th Century, there was quite an active banana fibre industry in Jamaica. Improved processes have made it possible to utilize banana fibre for many purposes such as rope, table mats and handbags. A good quality paper is made by combining banana fibre with that of the betel nut husk (Chandler, 1995).

Dried banana peel, because of its 30 to 40% tannin content is used to blacken leather. The ash from the dried peel of bananas and plantains is rich in potash and used for making soap. That of the burned peel of unripe fruits of certain varieties is used for dyeing (Ogazi, 1996)

CONCLUSIONS

West Africa is one of the major plantain-producing regions of the world, accounting for approximately 32% of worldwide. Meanwhile, bananas are also grown in West Africa, but they account for only 2.3% of worldwide. Bananas are more likely than plantains to be grown for export rather than for local consumption. Major constraints to banana and plantain production include pests and disease (such as the black leaf streak virus and nematodes), post-harvest losses, soil degradation, limited knowledge of best practices among smallholder farmers, lack of inputs, and limited labor availability.

Plantain production is dominated by men, but women play a key role in processing and marketing. Whereas plantain marketing is characterized by small-scale, widely dispersed producers, banana production in Cote d'lvoire and elsewhere in West Africa is generally more centralized, involving larger production firms and a more structured marketing and transportation system. Banana and plantain production enterprises in West Africa make significant contributions to local economies in the area of employment generation; contributions to national income and Gross Domestic Product (GDP); poverty alleviation; economic and industrial growth; and rural development. To obtain higher yield of these crops and sustainably, the following recommendations are proffered.

The effort of farmers should be collaborated with a good and adequate social infrastructure, like better transport systems and efficient extension services. Hence, the need for Government to formulate and implement policies targeted at improving infrastructures and providing market information outfit that disseminates information timely to marketers of banana and plantain. Furthermore, Government should set up or improve their fiscal and monetary policies that stabilize price especially for consumable products like banana and plantain.

In addition, future research on plantains and bananas should address the issue of intensive cropping and nutrient and water requirements to increase productivity both on-station and on-farm with farmers' participation. This will assist in meeting the ever-increasing demand of these crops by both household consumers and the new small-scale industries. Finally, the network among marketers could be improved to limit the influence of middle men (rural assemblers) so as to reduce the final cost of banana and plantain that reaches the ultimate consumer. Given that the higher the number of interventions between producer and consumer, the greater the final price becomes.

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Utilization of Plantain and Banana By-Products for Sustainable Development: A Review

Ayodawha, E. V.
Department of Food Science and Technology, Obafemi Awolowo University, Ile-Ife, Nigeria
Corresponding author's email: ayodawhavictory@gmail.com

ABSTRACT

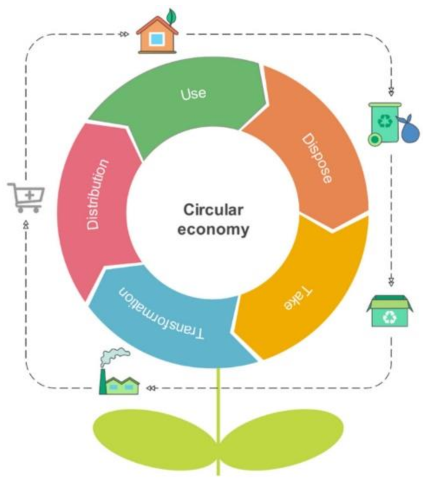
The potential of banana and plantain in supporting the circular economy, particularly within the food industry, cannot be overemphasized. These crops are bioresources, typically cultivated in tropical regions, and can serve as valuable renewable resources, transforming agricultural waste into bio products with applications across construction, packaging, textiles, and bioenergy sectors.

This paper highlights the benefits of using banana and plantain bye-products in reducing waste, enhancing resource efficiency, and economies. Additionally, the role of urban centers, especially within the context of Nigeria, is discussed as crucial in reshaping food systems through waste reduction, local production, and sustainable distribution models. The study emphasizes that such circular practices can significantly contribute to food security, environmental sustainability, and economic resilience.

Keywords: Circular economy; banana and plantain bio-resources; agricultural waste; urban food systems; and waste management.

INTRODUCTION

The increasing global emphasis on sustainable development has led to the critical need for effective strategies in bioresource management. The circular economy framework, which seeks to minimize waste and maximize the value of resources through reuse, recycling, and regeneration, offers a promising alternative to the traditional linear economy. i.e, an economic model based on the take-make-dispose approach. In this system, raw materials are extracted (take), processed into products (make), and ultimately discarded as waste after use (dispose). This model prioritizes continuous production and consumption without significant concern for resource regeneration or environmental impact. See figure below.



Within this context, banana and plantain have emerged as valuable agricultural bio-resources contributing to building a sustainable circular economy because of its culinary, health, and industrial benefits. These crops, widely cultivated in tropical regions, present significant potential not only as food sources but also as renewable materials for various industrial applications (Jones & Smith 2020).

Banana and plantain generate substantial biomass, from peels, stems, Sucker, leaves, and fruits, some of which are often discarded as agricultural waste. As of 2019, global banana production was estimated at approximately 117 million metric tons. Notably, nearly 60% of the banana plant's biomass remains as waste after harvesting, translating to about 70.2 million metric tons of residual biomass annually (Sharma et al. 2021).

However, recent advancements in bio-based technologies have demonstrated that these by-products can be transformed into valuable materials for use in construction, packaging, textiles, and energy production. By converting waste into high-value products, banana and plantain can reduce environmental impacts, contribute to resource efficiency, and foster local economic development (FAO, 2021)

This paper explores the potential of banana and plantain as bio-resources in promoting a circular economy. It examines their applications in various industries, their environmental benefits, and the economic opportunities they offer for sustainable development. In doing so, the study highlights the role of these bio-resources in reducing reliance on finite materials and advancing global efforts toward achieving a zero-waste economy (Singh & Mukherjee, 2022).

The Relationship Between the Circular Economy and the Food Industry

There is a thin line between global effort for sustainable development and ensuring food security. There is a need to accelerate the attainment of food security and sustainable development as global populations grow and resource pressures mount. Bioresources like banana and plantain should be harness to align with the circular economy model; minimizing waste, promoting resource efficiency, and creating value from the waste, and by-products. These crops play a vital role in rethinking how agricultural waste can be transformed into sustainable materials and inputs for other industries (FAO, 2019)

Food and the Circular Economy

Nigeria is among the top producers of plantains globally, with an annual production of approximately 2.72 million metric tonnes, making it the leading producer in Africa and the fifth worldwide (FAO 2021). This substantial production underscores the high domestic demand and consumption, especially in urban centers.

In urban areas like Lagos, bananas and plantains are dietary staples. A study focusing on Nsukka Urban in Enugu State revealed that these fruits are consumed across various income levels, reflecting their widespread acceptance and importance in Nigerian diets (Onyekwere et al. 2020). While specific consumption figures for Lagos are limited, the city's significant population suggests a high volume of banana and plantain consumption.

This widespread consumption of bananas and plantains in these urban areas has led to considerable organic waste, primarily from peels and spoiled fruits. In Nigeria, it is estimated that over 40% of root crops, fruits, and vegetables are wasted (Olayemi et al. 2022). Given the high consumption rates of bananas and plantains, a substantial portion of this waste can be attributed to these fruits.

In Lagos, the waste generation rate is estimated at 0.65–0.95 kg per person per day (Adekunle & Ojo 2021). With a population exceeding 18 million, this translates to approximately 11.7 to 17.1 million kilograms of waste daily. Organic waste, including banana and plantain peels, constitutes a significant portion of this total.

Cities as Catalysts for Changing the Food System in Nigeria: A Statistical Perspective

Nigeria, as Africa's most populous country, faces significant challenges and opportunities in reshaping its food system through urban centers. With more than 50% of Nigeria's population now living in urban areas, cities such as Lagos, Abuja, Kano, and Port Harcourt are central to food consumption, distribution, and waste management. These cities have the potential to drive innovation in agriculture, improve food access, reduce waste, and develop sustainable food policies (Adebayo & Okeke, 2023).

Below, the relationship between urbanization and food systems transformation in Nigeria is explored,

Reducing Food Waste

Food waste remains a significant issue in Nigerian cities. In Lagos, for instance, food waste accounts for nearly 50% of the total waste generated in the city. However, efforts to address food waste are slowly gaining traction. NGOs and startups, such as Lagos Food Bank Initiative, are working to reduce food waste by redistributing surplus food to underserved communities. Additionally, the Lagos State Waste Management Authority (LAWMA) is encouraging composting and recycling of organic waste to turn food scraps into fertilizer for urban farming initiatives (Lagos State Waste Management. 2019).

Key Statistics:

Food waste: Lagos produces around 13,000 tons of waste per day, a significant portion of which is food waste.

Composting potential: If 50% of Lagos's organic waste were composted, it could generate around 6,500 tons of compost daily, improving soil health and supporting urban Agriculture.

Government and Industry Efforts in Adding Value to Banana and Plantain Waste

Governments and industries worldwide are increasingly recognizing the potential of banana and plantain waste as valuable resources for promoting economic growth and environmental sustainability. Through various initiatives, policies, and industrial innovations, they are transforming these by-products into valuable commodities across sectors such as bioenergy, agriculture, and food processing.

1. Government Initiatives and Policies.

- **Funding and Research Support**: Governments in major banana-producing countries, including India, Brazil, and Nigeria, have allocated grants and funding to research institutions to explore innovative applications for banana and plantain waste (FAO, 2020). International organizations like the Food and Agriculture Organization (FAO) and the United Nations Industrial Development Organization (UNIDO) also support global efforts to reduce agricultural waste through sustainable development programs (UNIDO, 2019)**.**

- **Waste-to-Wealth Programs**: National agricultural policies in countries such as Ghana and Cameroon encourage small and medium enterprises (SMEs) to engage in recycling banana and plantain waste (Adjei & Boateng, 2021). Government-backed cooperatives assist farmers in processing banana peels into animal feed, organic fertilizers, and biogas, thereby promoting sustainable practices and additional income streams (Mensah, 2022).

- **Environmental Regulations**: Governments have implemented waste management policies to ensure the proper disposal and utilization of agricultural by-products. The European Union (EU) and the United States Department of Agriculture (USDA) have established guidelines aimed at reducing food waste, including incentives for companies that convert fruit waste into valuable products (USDA, 2021; European Commission, 2020).

2. Industrial Innovations and Commercial Applications.

- **Biodegradable Products**: Innovative companies are utilizing banana fibers to manufacture eco-friendly products. For instance, Kodu Technology, a Ghanaian agribusiness startup, produces naturally decomposable sanitary pads from banana and plantain stems (Owusu, Asante & Amankwah, 2023). This initiative not only addresses environmental concerns but also tackles period poverty by providing affordable sanitary products.

- **Food Industry Applications**: Banana flour, made from green bananas, serves as a gluten-free alternative to wheat flour and is rich in resistant starch. Its production offers a solution to high rates of waste among banana crops, as culled green bananas unsuitable for sale can be utilized, thereby reducing waste and providing economic benefits to producers (Adekunle, Olatunji & Eze, 2022).

- **Genetic Innovations to Reduce Waste**: Biotechnology companies are developing gene-edited non-browning bananas to combat food waste. For example, Tropic, a Norwich-based biotech company, has created a banana that stays fresh for 12 hours after peeling and is less prone to browning during harvesting and transportation (Jones, Richards & Martinez, 2021). Such innovations aim to extend shelf life and reduce waste in the supply chain.

Integrating Banana and Plantain as Bio resources for Building a sustainable circular economy

Banana and plantain crops present an untapped potential to foster a more sustainable circular economy. As agricultural staples in many parts of the world, these crops generate not only food but also large quantities of biomass in the form of peels, stems, leaves, and unused fruits, which are often discarded. By integrating banana and plantain into the circular economy, these bio-resources can be harnessed to create value-added products, reduce environmental waste, and promote sustainability across multiple sectors (Osei and Agbozo, 2022).

Here are several ways in which banana and plantain can be integrated into a circular economy:

1. Utilization of Agricultural By-products:

One of the fundamental principles of the circular economy is the reuse of materials that are traditionally considered waste. In the case of banana and plantain, their peels, stems, and leaves can be repurposed for a variety of applications. For example:

Peels: Banana and plantain peels are rich in nutrients and can be processed into organic fertilizers, biofuels, or animal feed. These uses divert agricultural waste from landfills, reducing methane emissions and creating a closed-loop system that enhances resource efficiency. See Table. 1.

Fibers: Banana stems and plantain leaves contain strong fibers that can be extracted and used to make biodegradable textiles, ropes, and paper. These materials provide an eco-friendly alternative to synthetic products derived from non-renewable resources like petroleum. (FAO, 2019)

2. Bioenergy Production:

The organic waste from banana and plantain farming can also be transformed into renewable energy sources, such as biogas. Anaerobic digestion of banana and plantain residues produces methane, which can be used for cooking, heating, or electricity generation, reducing reliance on fossil fuels. This not only provides an additional energy source but also aligns with the circular economy's emphasis on regenerative energy systems (Agbor and Diko, 2019).

3. Sustainable Packaging:

One of the most innovative applications of banana and plantain by-products is their use in developing sustainable packaging solutions. The fibrous structures in the plants can be processed into biodegradable packaging materials that replace single-use plastics, a significant contributor to global pollution. These natural packaging solutions decompose quickly, contributing to waste reduction and environmental sustainability, while also providing economic opportunities for industries seeking eco-friendly alternatives. (Kalia and Verma, M 2021)

4. Composting and Soil Fertilization:

As natural bio-resources, banana and plantain residues are ideal for composting, which can significantly improve soil health and agricultural productivity. The use of organic compost derived from these plants reduces the need for synthetic fertilizers, promotes soil biodiversity, and returns essential nutrients back to the soil, completing the natural cycle of regeneration. This practice supports the goals of the circular economy by encouraging closed-loop systems where organic matter is continuously reused (Zubair and Nascimento 2020).

5. Nutritional and Pharmaceutical Benefits:

Banana and plantain plants offer valuable nutrients, antioxidants, and compounds with medicinal properties. Their by-products can be processed into dietary supplements or natural health products, offering an additional revenue stream for farmers and contributing to human health. This integration of health benefits ties into the circular economy's focus on maximizing the value of resources throughout their lifecycle (Reddy and Prabihu, 2021). See Table 1.

Table 1: Nutritional and Pharmaceutical Benefits

By-Product	Nutritional Benefits	Pharmaceutical Benefits	References
Peels	High in fiber, potassium, and antioxidants like flavonoids and polyphenols.	Antimicrobial, anti-inflammatory, aids in wound healing and diabetes management.	(Adekunle et al., 2022; FAO, 2020)
Leaves	Contains calcium, iron, and magnesium.	Used in traditional medicine for fever reduction and pain relief.	(Owusu et al., 2023; Mensah, 2022)
Stems (Pseudo stems)	High in dietary fiber, promotes gut health.	Helps regulate blood sugar, potential use in treating kidney disorders.	(Jones et al., 2021; USDA, 2021)
Banana Sap	High in bioactive compounds with antimicrobial properties.	Aids in wound healing and stomach ulcer treatment.	(Adekunle et al., 2022; FAO, 2020)
Fibers	Contains cellulose, valuable for dietary fiber supplements.	Used in drug delivery systems and biodegradable	(Owusu et al., 2023; Mensah , 2022)

medical applications.

Source: (Reddy and Prabihu, 2021)

6. Economic and Social Impact:

Integrating banana and plantain into the circular economy framework can provide significant socio-economic benefits, especially for rural communities in banana-growing regions. By creating new markets for agricultural waste, farmers and small-scale enterprises can increase their income, promote local entrepreneurship, and reduce reliance on traditional economic models that exploit finite resources. This sustainable approach also encourages job creation in emerging industries such as bio-material production, composting, and renewable energy (Olawale, & Ajani 2020).

1. COMMERCIALIZATION OF BANANA WASTE PRODUCTS

- **Investment in Bio-Based Industries**: There is a growing demand for **biodegradable plastics, biofuels, and organic fertilizers** derived from banana and plantain waste.
- **Expansion of Functional Food Markets**: **Incorporating** banana peels in nutritional supplements and energy bars presents a new market opportunity.**2. Technological Advancements**
- **Improved Extraction Methods**: The development of enzymatic and nanotechnology-based extraction techniques can enhance the efficiency of bioactive compound isolation.
- **Automation in Processing**: The adoption of machine learning and robotics in waste processing can improve product quality and scalability.

3. POLICY AND SUSTAINABILITY INITIATIVES

- **Government Incentives for Circular Economy Models**: Policies promoting waste-to-value initiatives can drive industry adoption.
- **International Collaboration**: Partnerships between **research institutions, governments, and industries** can enhance knowledge-sharing and commercialization of banana by-products.

CONCLUSION

The integration of bio resources, such as bananas and plantains, and the role of urban centers as catalysts for transforming food systems are crucial components in building a sustainable circular economy. Through innovative practices in agriculture, waste management, and food distribution, cities have the potential to address the pressing challenges of food security, environmental degradation, and socio-economic inequality.

The food industry, particularly with the inclusion of bio resources like bananas and plantains, presents numerous opportunities for achieving sustainability goals. These crops offer not only nutritional benefits but also potential for bio product development and waste valorization, aligning perfectly with the principles of a circular economy. By optimizing resource use, reducing food waste, and creating closed-loop systems, the integration of these bio resources can contribute to a greener, more sustainable food system.

Moreover, cities, as hubs of population, economic activity, and innovation, are uniquely positioned to lead the charge in transforming food systems. With urban agriculture, advanced distribution models, and policies targeting sustainability, cities can mitigate the environmental impacts of food production and consumption. In Nigeria, where rapid urbanization is driving significant changes in food consumption patterns, there is a growing need for strategies that reduce waste, enhance local food production, and ensure equitable access to healthy, nutritious food.

Ultimately, the shift toward a circular economy in the food sector, supported by the strategic use of bio resources and the proactive involvement of cities, holds immense promise for fostering global food security and environmental sustainability. Through this approach, nations like Nigeria can move closer to a future where economic growth is decoupled from resource depletion, and the well-being of both people and the planet is prioritized. The collaborative efforts of governments, industries, and urban communities will be critical in achieving these transformative goals.

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Conversion of Overripe Plantain into Wine to Reduce Post-Harvest Loss

[1]Akala, J. M., [1]Oyelakin, J., [1]Malomo, A. A., [2]Olaniran, A. F.

[1]*Department of Food Science and Technology,*
[2]*Obafemi Awolowo University, Ile – Ife, Nigeria.*
Lank Mark University, Omu-ran, Nigeria

Email of the Corresponding author:
Joyakala67@gmail.com

ABSTRACT

Plantain wine, locally known as *Agadagidi*, is an alcoholic beverage derived from the fermentation of overripe plantains. This process effectively reduces waste by transforming a highly perishable crop into a valuable product. As a traditional Nigerian fermented beverage, *Agadagidi* exemplifies the principles of a circular economy by repurposing agricultural byproducts to minimize food waste. The natural fermentation of *Agadagidi* requires minimal energy inputs, making it a sustainable alternative to conventional alcoholic beverages. By keeping resources in use for longer periods, this production method aligns with waste prevention strategies and promotes sustainable food practices. Additionally, the antioxidative activity of plantain wine contributes to its potential health benefits. Exploring the production and commercialization of *Agadagidi* can open new pathways for sustainable food systems while preserving cultural heritage. As consumer interest in natural, locally sourced, and eco-friendly alcoholic beverages grows, plantain wine presents an opportunity to integrate tradition with modern sustainability efforts.

Keywords: Plantain wine, *Agadagidi*, antioxidative activity, waste prevention, alcoholic beverage

INTRODUCTION

Wines are made when healthy grapes undergo a typical alcoholic fermentation and then aged. A large number of other fruits such as peaches, pears, plantain, blueberry and so forth may be fermented for wines, but in these instances, the wine is named by the fruit, such as peach wine, pear wine, plantain wine and the like. Because fruits already contain fermentable sugars, the use of exogenous sources of amylases is not necessary (James *et al.*, 2005).

Winemaking is an ancient bioprocess. Scientific understanding of the process commenced with the studies of Louis Pasteur, who demonstrated that wines were the product of alcoholic fermentation of grape juice by yeasts. Since then, winemaking has developed into a modern, multinational industry with a strong research and development base in the disciplines of viticulture and enology. Viticulture concerns the study of grapes and grape cultivation, and enology covers postharvest processing of the grapes, from crushing through fermentation to packaging and retailing of the wine (James *et al.*, 2005).

Enology, the scientific study of wine (from the Greek oinos, wine, and ology, the science of), focuses on wine production, starting with grape harvesting (Smith, 2020). Following collection, grapes undergo crushing to extract the liquid, known as must, which subsequently undergoes fermentation (Jones and Johnson, 2018). In the winemaking process, the biochemical transformation of juice into wine transpires through the enzymatic breakdown of fruit sugars (fructose and glucose) by yeast, specifically *Saccharomyces cerevisiae* var. ellipsoides. This breakdown proceeds from sugars to acetaldehyde and culminates in the production of alcohol (Jones and Johnson, 2018). During wine production, grapes are crushed to release the juice, or must. A pure culture of wine yeast is then introduced as a starter culture, cultivated in sterilized or pasteurized grape juice (Brown *et al*., 2019). Initially, the presence of air facilitates rapid aerobic yeast growth. Subsequently, as the available air diminishes, anaerobic conditions prevail, initiating alcohol production (Smith and White, 2021).

Plantains (*Musa paradisiaca*) are a group of starchy, firm-fleshed bananas that are typically cooked before eating (Watson *et al.*, 2002). They are a staple food in many tropical and subtropical regions and are an important source of carbohydrates, vitamins, and minerals. Plantains are a good source of carbohydrates, providing about 100 calories per 100 grams. They are also a good source of potassium, vitamin A, and vitamin C.

Plantains are also a good source of fiber, which can help to promote digestive health. Plantains are typically cooked before eating. They can either be boiled, baked, fried, or grilled. Green plantains are starchy and have a neutral flavor, while ripe plantains are sweeter and have a slightly banana-like flavor. Plantains are often used in savory dishes, such as stews and fritters, but they can also be used in sweet dishes, such as desserts. The ripening of plantains is controlled by a complex interplay of hormones and enzymes plantains. As it ripens, the starch in the fruit is converted to sugar in the process mediated by the enzyme amylase. The conversion of starch to sugar results in a decrease in the fruit's firmness and an increase its sweetness (Shigemoto, Kazuyoshi *et al.*, 2006).

Plantains (*Musa spp.*, AAB genome) are plants that yield starchy fruits that must be processed before eating (Marriot and Lancaster, 1983; Robinson, 1996). More than fifty per cent of the world's plantains are produced in Africa, according to estimates (FAO, 1990). The plantain, a perennial ratoon crop with a short gestation time, plays a key function in the rapid production of food. After yam (*Dioscorea spp*) and cassava (*Mahihot escultenta*), the crop was the third most popular starchy staple. It is a significant source of carbohydrates for almost 50 million individuals.

In Nigeria, fruits are used as food in one way or another at every stage of development, from immature to overripe. The young green fruits are dried, peeled, sliced, and ground into a powder and eaten as "plantain fufu." Ripe or unripe, the mature fruits are eaten roasted, baked, steamed, boiled, pounded, or sliced and deep-fried into chips. Overripe plantains are processed into wine or spiced with chilli pepper, fried with palm oil and served as snacks (‘dodo-ikire’). Plantain fruits are used as a composite material in the manufacturing of bread, biscuits, infant food (such as "Babena" and "Soyamusa"), and other products (Ogazi, 1996; Akyeampong, 1999).

According to FAOSTAT, plantain production in West Africa is considerably higher than banana production. Post-harvest losses for plantains have a number of causes, including rough handling, harvesting, harvesting at maturity just before the fruit ripens, lack of processing options, contamination from spoiled fruits, and inadequate storage and transportation (Zhang *et al.*, 2005; Tchango *et al.*, 2009; Adeniji *et al.*, 2010). High temperature and humidity in West Africa combined with poor storage options also shorten the shelf life of plantains, leading to increased rot and waste. (Akinyemi *et al*., 2010). Estimated post-harvest losses are as high as 40% in Nigeria (Olurunda, 1996; Odemero, 2013).

Though plantains are produced all year round, the major harvest comes in the dry season (November to February), when most other starchy staples are unavailable or difficult to harvest. As such, it is crucial in helping to close the gap in hunger and providing farmers with cash through plantain sales (Wilson, 1986). Plantain peels are fed to cattle in Nigeria, and the dried peels are used to make soap. The dried leaves, sheath, and petioles are utilized as roofing material, sponges, and binding materials. Moreover, food can be packaged, marketed, and served using plantain leaves (Wilson, 1986).

Plantain wine *(Agadagidi*), a cloudy effervescent sweet-sour taste typical of African traditional alcoholic beverage is made from overripe plantain through fermentation. It is common in south-western part of Nigeria (Omajasola *et al*., 2012). The fermentation of overripe plantain to produce "*Agadagidi*" is a waste-prevention process of plantain. Plantain is a perishable crop which has much less value when it is overripe; hence it is used for wine production (Akinyanju and Oyedeji, 1993; Sanni *et al*., 1999; Sanni and Oso, 2006). Many Indigenous fermented foods and beverages are faced with various challenges among which are short self-life and microbial-induced spoilage within few days of production. This development can be attributed to uncontrolled fermentation and the crude method used for the production of such food and beverages; natural fermentation of overripe plantain is carried out in some parts of Nigeria to produce *Agadagidi*. (Abiose and Adedeji, 1994).

PLANTAIN WINE PRODUCTION

Plantain wine, a traditional beverage with deep cultural roots in Africa and the Caribbean, is produced through the fermentation of ripe plantains. The process of transforming plantains into wine has evolved over time, blending traditional techniques with modern practices to enhance quality and safety.

Historical context and cultural significance

The history of plantain wine production can be traced to regions where plantains are widely cultivated, such as Southeast Asia, Africa, and the Caribbean. In East Africa, plantains are a staple crop, often used for making fermented beverages in places like Uganda and Tanzania. The production methods vary, but the cultural significance remains, reflecting the deep connection between the people and the land.

In many communities, plantain wine serves as a symbol of hospitality and is often consumed during celebrations, rituals, and gatherings. Its production is not just a means of generating alcohol; it embodies community cooperation, with families often coming together to harvest, prepare, and ferment the plantains. The beverage's unique flavours and aromas contribute to its status as a cherished cultural artifact, passed down through generations.

Traditional and modern practices

The production of plantain wine involves distinct traditional and modern approaches, each influencing the final quality and flavor of the wine.

Traditional practices typically begin with the selection of ripe plantains, which are peeled and prepared by natural methods such as using ash or burning leaves. Fermentation is initiated spontaneously, relying on wild yeasts from the plantain skins and surrounding environment. This process unfolds in earthenware pots or wooden barrels, sometimes lasting several weeks or months. Flavoring agents such as spices and herbs may be added, while clarification is done using natural filtration techniques like leaves or settling.

Modern methods introduce commercially available yeast strains to ensure consistent fermentation. Advanced temperature control and sanitation measures help improve wine quality and reduce spoilage. Additionally, additives and preservatives may be used to stabilize and clarify the wine, although this can affect the natural appeal for some consumers. These practices highlight the ongoing evolution in winemaking, where traditional knowledge meets scientific innovation.

Ingredients and fermentation process

Ripe plantains are the primary ingredient in plantain wine production, prized for their sugar content and fermentable quality. Water serves as a solvent, while yeasts – either naturally occurring or commercial strains – drive the fermentation. Optional ingredients like spices, herbs, or other fruits can be incorporated to enhance the flavor profile.

The fermentation process begins with preparing the plantains by peeling and mashing them, followed by adding water for dilution. The mixture is then fermented either spontaneously or through inoculation with selected yeast strains. During the primary fermentation phase, yeasts convert plantain sugars into alcohol. Some recipes may include a secondary fermentation stage for flavor refinement. The final steps involve clarifying the wine and bottling it for consumption.

Quality control during fermentation is vital. Temperature fluctuations can significantly impact yeast activity, leading to variations in flavor and alcohol content. Regular monitoring of pH levels and specific gravity helps producers make informed decisions about fermentation duration and potential interventions.

Factors influencing wine quality

The quality of plantain wine is determined by multiple factors, including the choice of plantain variety, ripeness, water quality, and yeast selection. Proper temperature regulation and nutrient availability are crucial for a smooth fermentation process. Hygiene during production also plays a significant role in preventing contamination and ensuring product safety.

Additionally, the geographical region where plantains are grown can influence the final product's flavor profile. The soil composition, climate, and cultivation practices contribute to the characteristics of the fruit, ultimately impacting the taste and aroma of the wine. Understanding these nuances allows producers to create distinct and high-quality beverages that reflect their unique terroir.

Challenges and opportunities

Plantain wine production faces several challenges, such as consistency in quality and market reach. Traditional methods often lead to variations in flavor and alcohol content, while limited access to modern equipment restricts commercial expansion. Overcoming these barriers through training, quality standards, and distribution networks can enhance production and broaden consumer access.

The unique flavor of plantain wine offers an opportunity to tap into niche markets. Promoting sustainable cultivation and emphasizing cultural heritage can appeal to consumers seeking authentic experiences. Expanding production can also provide economic benefits, creating new income sources in plantain-growing regions.

Furthermore, as consumer preferences shift toward organic and naturally produced beverages, plantain wine could position itself as a viable option. Highlighting the health benefits of fermented foods, including probiotics found in certain types of plantain wine, can also attract health-conscious consumers.

Fermentation in plantain wine production

The fermentation process, driven by yeasts like *Saccharomyces cerevisiae*, transforms plantain sugars into alcohol and other compounds that shape the wine's characteristics. Factors such as sugar content, temperature control, pH levels, and nutrient availability significantly impact yeast activity and fermentation outcomes. Optimal conditions ensure a balanced process that enhances flavor while minimizing spoilage risks.

Monitoring fermentation dynamics, such as the production of carbon dioxide and the evolution of flavor compounds, allows producers to fine-tune their processes. This careful observation can lead to innovative approaches, such as the use of controlled fermentation environments or specific fermentation vessels designed to enhance flavor extraction.

Conclusion

Plantain wine production, deeply rooted in tradition, has the potential to evolve through modern innovations, creating a unique beverage that blends cultural heritage with contemporary winemaking techniques. Embracing this fusion can unlock new markets and economic opportunities while preserving the rich history of plantain wine as a distinct and culturally significant beverage.

As global interest in artisanal and culturally rich products grows, plantain wine stands at the forefront of this movement. By investing in quality production practices, enhancing marketing efforts, and building community awareness, plantain wine can thrive, offering consumers not just a drink, but a taste of history and culture in every sip.

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