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Effects of Postharvest Qualitative and Quantitative Losses and Improved Loss Reduction Technology (Waxing) on Commercial Cassava (*Manihot esculenta* Crantz) Processing

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Abstract

Cassava, a staple food in tropical and subtropical regions, faces significant postharvest losses during processing, which has detrimental effects on food security, economic sustainability, and agricultural productivity. This research was conducted in three commercial cassava processing facilities, utilizing three improved cassava varieties (TME-419, TMS-593 and TMEB-693), to assess qualitative and quantitative losses at different stages of the processing chain for gari, pupuru and fufu. Qualitative losses involved evaluating the deterioration of cassava quality attributes, while quantitative losses focused on measuring weight loss during processing. To address these losses, a novel loss reduction technology involving waxing, using food-grade paraffin wax produced from candlesticks, was implemented. Edible wax was applied to cassava roots to minimize moisture loss and prevent microbial spoilage. The effectiveness of the waxing treatment was evaluated by comparing quality attributes and weight loss between waxed and untreated cassava. The findings revealed significant qualitative and quantitative losses throughout commercial cassava processing, primarily due to moisture loss, enzymatic browning, and microbial spoilage. However, the application of waxing technology showed promising results in reducing these losses. After ten (10) days of storage, only the waxed TME-419, TMS-593 and TMEB-693 varieties had moisture left within them while the unwaxed cultivars had already decayed and deteriorated. Also, waxing led to decreased cyanide levels from 5.69, 4.57 and 2.52 mg/kg to 4.02, 4.08 and 1.11 mg/kg, respectively in the three varieties after ten days of storage. Waxed cassava exhibited improved texture, color retention, and extended shelf life compared to untreated cassava. Additionally, the weight loss of waxed cassava was significantly lower ($p<0.05$), indicating reduced postharvest losses. This study sheds light on the significant postharvest losses encountered in commercial cassava processing, and it introduces waxing technology as an innovative and effective approach to reduce these losses. The findings underscore the significance of implementing enhanced loss reduction technologies to improve the efficiency and sustainability of cassava processing. This, in turn, leads to enhanced food security and improved economic outcomes for communities that rely on cassava.

Keywords: *Cassava processing; loss reduction; waxing; qualitative indices; quantitative indices*

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1. Introduction

Starchy roots and tubers are commonly cultivated indigenous food security crops that dot the African agro-ecological landscape (Enujiugha, 2020; Osundahunsi *et al.*, 2016) and serve the energy and calorie needs of rural populations. These tuberous staples include yam (Bobadoye *et al.*, 2016), cassava (Isaac-Bamgboye *et al.*, 2020a), sweet potato (Abiodun and Enujiugha, 2021), cocoyam and some highly localized indigenous tubers (Gwer et al, 2018). Cassava (*Manihot esculenta* Crantz) is an important staple food in many tropical and subtropical regions and holds significant recognition as a 21st-century crop, particularly for smallholder farmers, due to its versatility, resilience to harsh growing conditions, and high caloric content, making it a crucial source of food security, income generation, and livelihood support for millions of people worldwide (Otekunrin and Sawicka, 2019). Cassava possesses certain inherent characteristics that make it particularly appealing to smallholder farmers in the southwestern region of Nigeria as a food crop. Firstly, it is abundant in carbohydrates, particularly starch, which grants it a wide range of applications. Additionally, cassava is readily available throughout the year, making it a preferable choice for ensuring food security compared to other food crops that are more seasonal, such as grains, peas and beans. In comparison to grains, cassava exhibits greater tolerance to poor soil fertility and is more resilient against drought, pests, and diseases. Moreover, its roots can be stored in the ground for several months after reaching maturity.

It is to be noted, however, that cassava is a perishable crop that is prone to postharvest physiological deterioration, which occurs within 24 to 72 hours after harvest, rendering the roots unpalatable and unsuitable for processing or consumption. In other words, cassava roots have a short shelf life because of their high moisture content when harvested, which results in natural biodegradation and huge losses. The postharvest losses are caused by a variety of factors, including mechanical damage, physiological degradation, enzymatic browning, water loss, and microbial spoilage. These losses not only affect the nutritional and market value of crops, but also lead to lower profitability for farmers and agribusinesses (Enujiugha, 2017). Traditionally, cassava processing involves peeling, grating, pressing, and drying the roots to produce various products such as flour, chips, and starch (Pele *et al.*, 2018). Unfortunately, each of these processing steps contributes to substantial losses if not managed properly. In dealing with the challenge of these gradual and intermittent postharvest losses, researchers and agriculturists have investigated a variety of post-harvest techniques and practices; and one of such legitimate and widely studied techniques is waxing. The implementation of innovative postharvest handling, processing, packaging, and storage methods plays a crucial role in the effective production and utilization of cassava roots and their derived products. The successful adoption of these postharvest technologies is expected to help maintain the quality and safety of the products, reduce postharvest losses, and ultimately contribute to improving food security (Opara, 2013).

Waxing is the application of a thin layer of wax to the surface of cassava roots to minimize water loss, reduce mechanical damage and extend shelf life. Wax treatments have been used successfully on crops such as citrus and apples, but their application to cassava processing has not been fully studied. Waxing involves heating food-grade wax (paraffin) to a temperature ranging from 140 ℃ to 160 ℃. The root tuber is then dipped into the wax for a brief period of 1-2 seconds (Zidenga *et al.*, 2012). However, the adoption of paraffin wax coating for cassava poses challenges for small-scale farmers in places like Nigeria. Precise temperature control and timing are crucial in order to avoid charring the root. Moreover, there is a growing concern about the use of non-biodegradable or inorganic chemical-based waxes, leading to a recent focus on utilizing waxes derived from renewable and biodegradable agricultural polymers. Edible films and coatings, made primarily from edible biopolymers and food-grade additives, are valuable materials (Enujiugha and Oyinloye, 2019; Olowolafe et al., 2023). The application of edible coatings can enhance the physical characteristics of food items, reduce the aggregation of food particles, and improve the visual appearance of the product (Enujiugha *et al.*, 2013; Baraiya *et al.*, 2015). The effectiveness of edible coatings in improving food quality and extending shelf life depends on several factors, such as the chemical composition, structure, coating formation method, and storage conditions of the food (Enujiugha and Oyinloye, 2019). In fresh produce, including cassava, the most critical factor contributing to quality deterioration is moisture loss (Atieno *et al.*, 2017).

Transforming cassava roots into various food products not only extends their shelf life but also enhances their value and minimizes postharvest losses (Uchechukwu-Agua *et al.*, 2020). Apart from chips, cassava can be processed into various products, including *fufu* (Babatuyi *et al.*, 2020), *pupuru* (Isaac-Bambgoye *et al.*, 2020a,b), *gari* (Stadlmayr *et al.*, 2012), starch (Pele *et al.*, 2018), and *lafun* (Sanusi *et al.*, 2017) on an extraordinary adventure in value-addition, with a view to preventing and/or reducing postharvest biodeterioration by scopoletin and other tissue-degrading compounds and microorganisms, as well as extending the shelf life of the freshly harvested roots. This study was therefore designed to evaluate the effectiveness of waxing in reducing postharvest losses of cassava tubers for improved yield of some cassava products.

2. Materials and Methods

Sources of Raw Materials

The different types of cassava roots (TMEB-419, IITATMSIBA070593, and TMEB-693) used and utilized in the study were procured from the International Institute of Tropical Agriculture (IITA). The candle sticks were obtained from Oja Oba in Akure, Ondo State, Nigeria. All reagents and chemicals employed in the experiment were of high quality, meeting analytical grade standards.

The Study Area

The study area comprised three cassava producing areas in Nigeria and covered by the project. They are Akure (A Local Government Area in Ondo State), Okitipupa (a Local Government Area in Ondo State) and Ilorin (A Local Government Area in Kwara State). Few random cassava processing plants were picked within the metropolis of each of these three areas and assessed for their manpower and other socio-demographic factors and how they affect the production of cassava and other cassava products.

Preparation of the cassava roots prior to waxing

Upon harvest, the cassava tuber roots, which varied in terms of varieties (TMEB-419, IITATMSIBA070593, and TMEB-693) and origins (Ondo and Ilorin), underwent a series of meticulous steps. Firstly, the roots were carefully sorted to eliminate any tubers that showed signs of decay or were already in a deteriorated state. Next, they were subjected to a thorough cleaning process to eliminate dirt, impurities, and any other foreign particles that could potentially contribute to decay even after waxing. To ensure optimal cleanliness, the roots were repeatedly washed and rinsed, meticulously removing any debris, earthy particles, or contaminants that might lead to decay. This diligent washing process aimed to guarantee that the roots were free from any substances that could compromise the effectiveness of waxing. After the thorough washing, the roots were rinsed once again and then allowed to dry. This drying stage served the purpose of removing excess water or moisture that could potentially interfere with the subsequent waxing process. By achieving an appropriate level of dryness, the roots were prepared and ready for the waxing procedure.

Preparation and application of the melted food-grade paraffin wax

The process of producing food-grade paraffin wax followed the methodology described by Waigumba et al. (2016) with minor modifications. The traditional dipping technique was employed to apply a layer of melted food-grade paraffin wax onto the entire root tubers of the respective cassava varieties used. To obtain the melted food-grade paraffin wax, the purchased candle sticks were heated until they reached a temperature range of 51.5 °C to 52.5 °C (125 °F to 127 °F). Subsequently, the washed, cleaned, and dried roots were immersed in the melted paraffin wax for 1-2 seconds at the same temperature range (51.5 °C to 52.5 °C or 125 °F to 127 °F) to achieve a smooth, thick surface coating, enhancing the glossiness of the roots.

Determination of proximate chemical composition of the cassava tubers

The proximate analyses of the samples were carried out using the official methods of analysis of the Association of Official Analytical Chemists (AOAC, 2012) and replicated three times. Moisture content was according to the air oven method (AOAC, 2012), whereby drying was done to constant weight; crude protein was determined using the micro-Kjeldhal method and the total nitrogen in the sample was multiplied by a factor 6.25 (AOAC, 2012); crude fat was extracted overnight in a Soxhlet extractor with n-hexane and quantified gravimetrically; ash content was determined in the sample by dry ashing in a muffle furnace at 550 ºC for 8 hours (AOAC, 2012); crude fibre was determined after digesting five grams (5 g) of fat-free sample in mixture of refluxing 1.25% sulphuric acid and 1.25% sodium hydroxide; and total available carbohydrates were determined by the difference method (subtracting the percent crude protein, crude fibre, crude fat, and ash from 100% dry matter). All analyses were carried out in triplicates. The energy values of the samples were obtained by multiplying crude protein, crude fat and carbohydrate contents by factors of 4, 9 and 4, respectively (Enujiugha and Ayodele-Oni, 2003).

Mineral Analysis

Mineral analysis was conducted following the methodology outlined by AOAC (2012). The ash obtained from the samples was subjected to digestion using 3 cm³ of 3 mol/L HCl. The volume was adjusted to the mark in a 100 cm³ standard flask using 0.36 mol/L HCl solution. The determination of mineral elements, including Sodium (Na), Potassium (K), Phosphorus (P), Magnesium (Mg), Iron (Fe), Zinc (Zn), and Calcium (Ca), was carried out using the AOAC (2012). Sodium and potassium were determined using the flame photometer; phosphorus was by the phospho-vanado molybdate (yellow) colorimetric procedure. The other minerals were determined using an atomic absorption spectrophotometer (Buck scientific 210 VGP, Bulk Scientific Inc., 06855 USA).

Determination of Cyanide Content

Some 50 mg of the sample was weighed out into a small flat-bottomed plastic vial (Egan *et al.*, 1998). Phosphate buffer (0.5 ml of 0.1 M at pH 4–10) was added, followed by exogenous enzyme. A picrate paper attached to a plastic backing strip (Bradbury *et al.*, 1999) was added and the vial immediately closed with a screw stopper. After about 16 h at 30 ºC, the picrate paper was removed and immersed in 5.0 ml water for not less than 30 min. The absorbance was measured at 510 nm and the total cyanide content (ppm) determined by the equation:

$$\text{Total cyanide content (ppm)} = \frac{396 \text{ x absorbance x } 100}{z}$$

where z = weight (mg) of sample.

Statistical Analysis

All data obtained via various measurements and determinations were subjected to one-way analysis of variance (ANOVA) in the SPSS software ver. 22.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation (SD). The significance of each experimental value was analyzed by Duncan's multiple-range test ($p < 0.05$).

3. Results and Discussion

Socio-demographic characteristics of the cassava processors

The analysis of the socio-demographic characteristics of the processors shows some interesting results as shown in Table 1. Based on the gender variable, Akure had zero male cassava processors followed by Okitipupa which had 2 male cassava processors that also accounted for 6.45% of the total population of 31, followed by Ilorin which also had 4 male cassava processors that also accounted for 11.76% of the population of cassava processors assessed, that is, 34 in number. Amongst the female cassava processors assessed, Ilorin had the highest number of them which also accounted for 88.24% of the total population of 30 in total. This is also followed by Okitipupa which also had 29 female cassava processors accounting for 93.55% of the total number of 31 within the area that was assessed. Then Akure had 20 female processors of cassava which also accounts for a complete 100% of the total cassava processor population of 20 that was assessed within the area. It can be deduced that under the variable of the gender, from the three study areas suggests that cassava processing is a female dominated activity. This was in line with the observation of Nuwamanya et al. (2019).

Table 1: Socio-demographic characteristics of commercial cassava processors in selected areas of Ondo and Kwara states, Nigeria

Variable	Akure (n=20)	Okitipupa (n=31)	Ilorin (n=34)
Gender			
Male	0	2 (6.45%)	4 (11.76%)
Female	20 (100%)	29(93.55%	30(88.24%)
Level of Education			
No formal education	10 (50%)	8 (25.80%)	17(50%)
primary	7(35%)	13(41.93%)	14(41.17%)
secondary	2(10%)	10(32.25%)	3(8.82%)
Post-secondary School	1(1%)	0	0
Family size			
1-3	6(30%)	4(12.90%)	8(23.53%)
4-6	8(40%)	12(38.17%)	15(44.12%)
7-9	6(30%)	13(41.93%)	11(32.35%)
10 and above	0	2(6.46%)	0
Duration as a processor			
1-5 years	6(30%)	8(25.80%)	17(50%)
6-10 years	7(35%)	9(29.03%)	11(32.35%)
10-15 years	3(15%)	11(35.48%)	6(17.65%)
More than 15years	4(20%)	3(9.67%)	6(17.65%)

Under the variable of level of education, Akure had 50% of its 20-population number without formal education (10 out of 20), Okitipupa had 25.80% out of its 31 in number of populations without a formal education while Ilorin had 50% out its total 34 in population number without formal education (17 out of 34 - half its population). The implication of this is that most of the processors are likely to readily adopt new technology and innovation. Further analysis shows that those who went through primary education in Akure are 7 out of 20 processors (35% out of the 20-population number), those who attended primary school in Okitipupa are 13 out of the 31 processors (41.93% of its total 31 in number population) and Ilorin had 14 out of its 34 in number population attended primary school (41.17% out of its 34 in number population). This also implies these processors would be to comprehend and master any nascent technology and innovations that maybe introduced to them to preserve long term cassava harvested. The secondary school education attendants amongst the processors in Akure was 2 (10%) out of the total number of 20 while Okitipupa had 10 (32.25%) out of its total number of 31 processors assessed and Ilorin had 3 (8.82%) out of its total 34 processors assessed who had attended secondary school. This further re-iterates that new technologies and innovations pertaining to cassava processing and engineering would be embraced greatly by these processors. And if some are reluctant to embrace such, overtime those who embraced them technologies would always educate and advised others to follow the bandwagon in other to drastically reduce post-harvest losses that has to do with cassava processing. For the post-secondary school education, only Akure could possess 1 (1%) out of a population of 20 while both Okitipupa and Ilorin had zero processors. This also signifies that there is the possibility of at least few processors that would have an open mind towards embracing newer technological advancements in nipping in the bud post-harvest deterioration within cassava produce.

Under the variable of family size, in the family size of between 1 and 3, amongst the 30 processors in Akure, there were 6 of them with such family size (that is 30%); Amongst the 31 processors in Okitipupa, there were 4 of them with such family size (that is 12.90%) and amongst the 34 processors in Ilorin, there were 8 of them which had such a family size (that is 23.53%). This implies that cassava processing can provide or generate an additional source of income for the family and even employment opportunities especially in a small-scale cassava processing operation. In the family size of between 4 to 6 persons, Ilorin had 15 (44.12%) out of 34 processors thriving under such family size; Okitipupa had 12 (38.17%) out of 31 processors surviving under such a family size; and Akure had 8 (40%) out of 20 processors thriving under such family size. This implies that there would be a much higher demand for additional income and employment generations amongst such a family size and engaging in cassava processing can contribute to skill development within the family. Family members involved in processing activities can acquire knowledge and expertise in various aspects of cassava processing, including harvesting, processing techniques, and product diversification too. In the family size of 7 to 9, Akure had 30% of its 20 processors (6 persons) surviving under such family size; Okitipupa had 41.93% of its 31 processors (that is 13 out of 31) working under such family size conditions and Ilorin had 32.35% of its 34 processors (that is 11 out of 34) thriving under such family size. This further implies that cassava processing can influence gender dynamics within the family. In some contexts, women may play a significant role in cassava processing, which can lead to the empowerment of women in decision-making processes, resource allocation, and income control. The allocation of time and responsibilities within the family can also be affected. Depending on the workload, family members involved in cassava processing may have to allocate a significant portion of their time to these activities, which could influence family interactions, leisure time, and the division of labor within the household. In the family size of 10 and above, only Okitipupa had 2 of its 31 processors with such a family size condition while both Akure and Ilorin had zero of such family size conditions. This also implies that cassava processing may foster social interactions within the family and the community. The involvement of family members in the processing activities can strengthen familial bonds, improve cooperation, and enhance shared decision-making processes. Furthermore, if cassava processing becomes a prominent economic activity in the community, it can create networks and partnerships among processors, leading to community development and cohesion.

Under the variable of duration as a processor, it can be observed from the Table 4.1 that for durations between one to five years (1 - 5), Akure had 6 (30%) out of its 20 processors who have been into cassava processing for less than 5 years; Okitipupa had 8 (25.80%) out of its 31 processors who have been engaging in cassava processing between the first and fifth year; and Ilorin had 17 (50%) out of its 34 processors who have been into processing of cassava for between 1 to 5 years. This implies that in all the communities of the study area which are also female dependent, gender roles and responsibilities may influence the duration of cassava processing. For example, when women are primarily responsible for cassava processing in these study areas, their other domestic duties and caregiving responsibilities might affect the time they can dedicate to processing cassava. This could potentially lead to longer processing durations. For durations as a processor for between six to ten years (6 - 10 years), Ilorin had 11 (32.35%) out of its 34 processors who have been in the business of cassava processing in such duration of years; Okitipupa had 9 (29.03%) out of its 31 processors who have into cassava processing for such number of years; and Akure had 7 (35%) out of its 20 processors who have been into cassava processing for such number of years. This signifies that the age of processors can also have an impact on the duration of cassava processing. Older processors might have accumulated knowledge and experience, enabling them to process cassava more efficiently and in a shorter time. Younger processors, on the other hand, may require more time to learn the necessary skills and techniques, leading to longer processing durations initially. For durations as a processor of 10-15 years, Akure had 3 (15%) out of its 20 processors who had been in the food processing of cassava for that length of years; Okitipupa had 11 (35.48%) out of its 31 processors who had been into the cassava processing for over such number of years; and Ilorin had 6 (17.65%) out of its 34 assessed processors who have been in cassava processing for such number of years. This implies that the higher the number of years in cassava processing, the greater the level of expertise over the span of many years and also the more advanced in intelligence would be in the use of technology and innovations surrounding cassava processing and know-how. Also, processors with higher incomes or better financial resources may be able to invest in more efficient processing methods, technologies, or skilled labor, resulting in shorter processing durations. For durations of more than 15 years, Akure had 4 (20%) out of 20 processors with such number of years as a cassava processor under their belt; Okitipupa had 3 (9.67%) out of 31 processors who have been in the cassava processing for over 15 years; and Ilorin had 6 (17.65%) out of 34 processors who also have been in the cassava processing of the food sector with more than 15 years under their belt. This further implies that the long number of years that these processors have been in the food processing section of cassava processing would attract a higher level of expertise which could be perceived from their degree of uniqueness and pristine expertise in the way they handle cassava roots to the cassava products obtained from processing. Also, long-term cassava processors who have been active in the industry for over 15 years may gain recognition, respect, and influence within their communities or professional networks. Their experience and expertise can make them trusted sources of knowledge and advice for other processors or aspiring individuals in the field. They may take on leadership roles, such as mentoring newcomers, providing training, or participating in decision-making processes related to cassava processing. And such processors are likely to have acquired extensive knowledge, experience, and skills in the field. They may have developed efficient processing techniques, mastered the intricacies of cassava processing, and gained expertise in managing various aspects of the process. This expertise can result in increased efficiency, higher productivity, and improved quality of processed cassava products. This in turn, may have established stable and sustainable livelihoods through their processing activities. They may have built strong networks with suppliers, buyers, and other actors in the cassava value chain, which can positively influence their socio-economic status. With increased experience, they may have better negotiating power, access to financial resources, and improved income generation potential.

Operational characteristics of the cassava processors

Table 2 shows some aspects of the operational characteristics of the cassava processors in both Ondo and Kwara states. Most of the processors sourced the raw cassava tubers from nearby markets and not from their own farms, because of the quantity needed for profitable processing. The dominant product among processors in Okitipupa was pupuru (38.7%), while the dominant product among processors in Ilorin and Akure was gari (52.9% and 50.0%, respectively. All the processors in the three operational areas covered by this study operated as personal household enterprises, mostly family business concerns. Furthermore, none of the processors was aware of the existence of any form of preservation method for freshly-harvested cassava tubers. This is indeed worrisome and could impact the path to sustenance of household livelihoods (Enujiugha, 2017). In all the processing centres, the harvested cassava tubers were promptly processed within twenty-four hours (24 h) to avoid postharvest rot.

Table 2: Some aspects of operational characteristics of cottage-sized cassava processing industries in Ondo and Kwara States, Nigeria.

S/N	Component in the questionnaires		Respondent		
			Okiti-pupa area (n=31)	Akure area (n=20)	Ilorin and environs (n=34)
1.	Source of cassava as a raw material	Own farm	3 (9.7%)	4 (20.0%)	2 (5.9%)
		Middle man	2 (6.4%)	2 (10.0%)	1 (2.9%)
		Market place	26 (83.9%)	14 (70.0%)	31 (91.2%)
2.	Types of products from cassava	Pupuru	12 (38.7%)	1 (5.0%)	1 (2.9%)
		Garri	8 (25.8%)	10 (50.0%)	18 (52.9%)
		Starch	1 (3.2%)	1 (5.0%)	2 (5.9%)
		Lafun	0 (0%)	0 (0%)	0 (0%)
		Fufu	2 (6.5%)	6 (30.0%)	8 (23.5%)
		Pupuru & Garri	5 (16.1%)	1 (5.0%)	0 (0%)
		Garri & Fufu	3 (9.7%)	1 (5.0%)	5 (14.7%)
3.	Ownership of business	Personal	29 (93.5%)	15 (75.0%)	31 (91.2%)
		Family	2 (6.5%)	5 (25.0%)	3 (8.8%)
		Cooperative	0 (0%)	0 (0%)	0 (0%)
		Partnership	0 (0%)	0 (0%)	0 (0%)
4.	Awareness of existence of any preservation method for cassava	Aware	0 (0%)	0 (0%)	0 (0%)
		Not aware	31 (100%)	20 (100%)	34 (100%)
5.	Length of time for processing cassava after harvest	Within 24 hr	28 (90.3%)	16 (80.0%)	30 (88.2%)
		Within 48 hr	3 (9.7%)	4 (20.0%)	4 (11.8%)
		Within 72 hr	0 (0%)	0 (0%)	0 (0%)
		Occasionally more than 72 hr	0 (0%)	0 (0%)	0 (0%)
6.	Preferred area of government assistance	Construction of processing centre	2 (6.5%)	1 (5.0%)	2 (5.9%)
		Provision of joint processing machinery	2 (6.5%)	2 (10.0%)	3 (8.8%)

For the processors in the three centres in both Ondo and Kwara states, the farmers' preferred level of government assistance should be in form of financial collaboration to uplift the processing machinery and factories generally. It was the general view of all the respondents that government's financial assistance would go a long way to improve their livelihoods and raise food security level. For the nation to achieve food and nutrition security, as well as household livelihoods threshold, food producers and processors are to be given full financial backing and assistance (Osundahunsi et al., 2016). This could come in the form of incentives through farmers' cooperative societies and other avenues for equitable assistance (Enujiugha, 2020). According to Osundahunsi et al. (2016), since over 80 percent of farmers are small holder farmers, and over 75 percent of women in rural areas are engaged in agriculture, these must be the major beneficiaries of government financial and other forms of material assistance. The present study has also supported the fact that there are more women than men involved in cassava processing into different products.

Cassava Processing into Gari

Table 3 depicts the quantitative losses of cassava root along its supply chain due to transportation and unit operations of production during gari processing. The result from the survey revealed that an average of 205.67 kg (from 195 kg of cassava in Okitipupa, 216 kg of cassava in Akure and 206 kg of cassava in Ilorin) of Cassava was processed into gari within a production cycle that took an average of five (5) days. The Costs incurred on transportation include the cost of transportation to the processing center after 1 -2 hours of purchase, the cost of loading, off-loading and transportation of gari to the market or home. Transportation cost accounted for 4.65% loss of the total cost from 3.7 kg loss in Okitipupa, 3.3 kg loss in Akure and 2.53 kg loss in Ilorin. Labour costs include cost of peeling, washing, grating/milling, holding period, pressing, sifting and frying of gari. Peeling operation accounted for 39.5 kg loss (20.28%) from the remaining 191.3 kg left off the transportation cost in Okitipupa; Peeling operation in Akure accounted from 58.8 kg loss (27.2%) from the remaining 219.3 kg left off the transportation cost; and Ilorin exhibited a 48.84 kg loss (23.71%) from the remaining 203.47 kg in its peeling operation, which was left off their transportation cost. In average, the peeling operation accosted about 49.05 kg (23.73%) loss in general.

The washing operation part of the gari processing cycle observed zero wastage and therefore zero loss was recorded. The grating or milling operation accosted an average of about 0.36% loss of the total labour cost. In Okitipupa, there was 0.88 kg loss from the remaining 151.8 kg off the peeling operation. In Akure, there was 0.6 kg loss from the remaining 153.9 kg off the peeling operation. In Ilorin, there was 0.72 kg loss from the remaining 154.63 kg off the peeling operation. The holding period of the gari processing cycle exhibited zero wastage and thereby zero losses in Okitipupa, Akure and in Ilorin. The pressing operation accosted an average of about 10.30% loss of the total labour cost. In Okitipupa, there was a 19.9 kg loss from the remaining 150.92 kg off the grating and holding period. In Akure, there was 23.4 kg loss from the remaining 153.3 kg off the grating and holding period. In Ilorin, there was 20.31 kg loss from the remaining 153.91 kg off the grating and holding period. The sifting operation was not carried out in Okitipupa but there would be some loss in either in moisture loss or microbial degradation according to a study by Udom et al. (2017). The sifting operation in Akure brought about 11.4 kg loss (5.3%) off the remaining 129.90 kg left from the pressing operation. In Ilorin, the sifting operation brought about 9.64 kg loss (4.68%) off the remaining 133.60 kg left from the pressing operation. In the garifying or final frying process there was some losses from each study area examined. In Okitipupa, there was 8.8 kg loss which accounts for about 4.49% off the remaining from the sifting process. In Akure, there was 8.3 kg loss which accounts for about 3.82% off the remaining 118.5 kg left off the sifting process. In Ilorin, there was 8.76 kg loss which accounts for about 4.25% off the remaining 123.96 kg left off the sifting process.

Table 3: Quantitative losses of cassava root along its supply chain due to transportation and unit operations of production during *gari* processing.

Component along processing pathway	**Okitipupa area**			**Akure area**			**Ilorin area**		
	Original Cassava quantity (Kg)	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**
Harvested cassava roots bought at the open market	195	-	-	216	-	-	206	-	-
Cassava roots brought to the processing site in a motor truck after 1-2 hr of purchase		3.7	1.9		3.3	1.52		2.53	1.23
Peeling operation		39.5	20.28		58.8	27.2		48.84	23.71
Washing		0	0		0	0		0	0
Grating		0.88	0.45		0.6	0.28		0.72	0.35
Holding period		0	0		0	0		0	0
Pressing		19.9	10.2		23.4	10.84		20.31	9.86
Sifting		NCO**	NCO**		11.4	5.3		9.64	4.68
Garifying		8.8	4.49		8.3	3.82		8.76	4.25
Overall Total:			**37.32**			**48.96**			**44.08**

**NCO= Not carried out

In the overall total, it can be deduced that in Okitipupa, only a total of 37.32% loss from the original 195 kg was lost to give the final gari product along the supply chain due to transportation and unit operations of production. In Akure, a total of 48.96% loss from the original 216 kg was lost also to give off the final gari product along its supply chain. While in Ilorin, a total of 44.08% loss was experienced along its supply chain to produce gari. The total values of outputs include the value of by-products (cassava peel) and gari. The implication of the loss analysis along the supply chain in these study areas is that processing cassava to gari is profitable because in all, less than (or equal to) of the original weight of cassava roots quantity was recorded as their return in investment and a relatively lower level of losses compared to a scenario with higher losses.

Cassava Processing into Pupuru

A study by Akinyele et al. (2020) described the processing of pupuru by stating that pupuru is traditionally cooked by soaking cassava in water for about 3-5 days to soften it. After fermentation, the wet mash is bagged and drained in a mechanical press. The fibers are hand-picked from the moromi, and the moromi is formed into balls or circles and placed over a fire to be smoked. The product obtained is a spherical substance with a beautiful brown color. Next, the outer shell is scraped off with a knife, and the inner white part is crushed and sieved to make a pulp (Akinyele et al., 2020). In the study area of Okitipupa as observed in Table 4, the processing stage for pupuru making starts with 208 kg of cassava roots. When the cassava roots are transported to the processing site in a motor truck, there is an observed loss of 2.6 kg (1.25%). This loss could be attributed to factors like moisture loss, bruising, or damage during transportation. During the peeling operation, 44.9 kg of cassava is lost, which accounts for 21.61% of the original quantity. Peeling involves removing the outer skin of the cassava roots, and this process results in a significant loss due to the removal of the outer layers. No losses are observed during the washing and steeping operation. This suggests that the cassava roots are handled carefully, and there is no significant loss of weight during these stages. The pressing operation results in a loss of 22.7 kg, which is approximately 10.89% of the original quantity. Pressing involves removing excess moisture from the cassava mash, and this process leads to some loss due to the removal of liquid. Also, during the sun drying process, a loss of 0.95 kg is observed, which accounts for 0.46% of the original quantity. Sun drying involves drying the cassava mash under the sun, and some weight loss is expected as the moisture evaporates. The final step of turning the cassava into pupuru results in a loss of 11.7 kg, which is approximately 5.63% of the original quantity. This loss could be due to various factors, such as moisture loss during further drying or the removal of impurities during the pupuru production process. Adding up all the observed losses, we have a total loss of 82.85 kg, which represents 39.84% of the original quantity of cassava roots (208 kg). This means that out of every 100 kg of cassava roots initially present, only approximately 60.16 kg is left after the entire pupuru production process. It is important to note that the losses can be influenced by factors such as the quality of the cassava roots, the proficiency of the workers, and the efficiency of the processing equipment.

Table 4: Quantitative losses of cassava root along its supply chain due to transportation and unit operations of production during *pupuru* processing.

Component along processing pathway	**Okitipupa area**			**Akure area**			**Ilorin area**		
	Original Cassava quantity (Kg)	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**
Harvested cassava roots bought at the open market	208	-	-	203	-	-	NA*	NA	NA
Cassava roots brought to the processing site in a motor truck after 1-2 hr of purchase		2.6	1.25		2.9	1.44			
Peeling operation		44.9	21.61		41.5	20.43			
Washing		0	0		0	0			
Steeping		0	0		0	0			
Pressing		22.7	10.89		22.4	11.02			
Sundrying		0.95	0.46		NCO**	NCO**			
Pupurufying		11.7	5.63		10.6	5.24			
Overall Total:			**39.84**			**38.13**			

*NA= Not available; **NCO= Not carried out.

In the study are of Akure, the process starts with 203 kg of cassava roots. When the cassava roots are transported to the processing site in a motor truck, there is an observed loss of 2.9 kg (1.44%). This loss could be attributed to factors like moisture loss, bruising, or damage during transportation. During the peeling operation, 22.4 kg of cassava is lost, which accounts for 11.02% of the original quantity. Peeling involves removing the outer skin of the cassava roots, and this process results in a loss due to the removal of the outer layers. No losses are observed during the washing and steeping operation. This suggests that the cassava roots are handled carefully, and there is no significant loss of weight during these stages. The pressing operation results in a loss of 22.7 kg, which is approximately 10.89% of the original quantity. Pressing involves removing excess moisture from the cassava mash, and this process leads to some loss due to the removal of liquid. No data is provided for the sun drying operation. Therefore, we cannot determine the exact loss or absence of loss during this stage. The final step of turning the cassava into pupuru results in a loss of 10.6 kg, which is approximately 5.24% of the original quantity. This loss could be due to various factors, such as moisture loss during further drying or the removal of impurities during the pupuru production process. Adding up all the observed losses, we have a total loss of 58.6 kg, which represents 28.87% of the original quantity of cassava roots (203 kg). This means that out of every 100 kg of cassava roots initially present, approximately 71.13 kg is left after the entire pupuru production process. However, based on the available data generated and observed, the overall losses amount to 38.13% of the original quantity of cassava roots. These losses can also be influenced by factors such as the quality of the cassava roots, the proficiency of the workers, and the efficiency of the processing equipment. In the study area of Ilorin, there was no data generated because there were available cassava roots on purchase from the stipulated chosen area.

Based on the observed losses obtained in the overall, and due to the reason, that less than 50% losses is extracted from the total processes involved in pupuru production, if all thigs being equal and proper, it implies both in Okitipupa and Akure or anywhere in the world the business of pupuru making would generate a sizable amount of profits and income. Although this is based on how those losses are well managed and eliminated, the business of pupuru would be a very good lucrative business.

Cassava processing into fufu

As explained in a study by Owolarafe et al (2018), the traditional method of producing fufu involves several unit operations. First, the cassava tubers are peeled and washed. Then, they are cut into thick chunks and soaked in water, either in earthenware pots or in a slow-flowing stream, for a period of 4-5 days. During this time, the tubers undergo fermentation, softening, and produce a distinct retted cassava meal. After the soaking period, the softened tubers are disintegrated in clean water. The resulting mixture is then sieved to remove any solid particles, and the liquid is allowed to settle. This settling process allows for the separation of water from the sediment. The sediment that settles at the bottom is the raw fufu, ready for further processing or consumption (Owolarafe et al., 2018). In Table 5, the quantitative losses of cassava root along its supply chain due to transportation and unit operations of production during fufu processing, is described with data generated from the study areas. In the Okitipupa study area, the process begins with 188 kg of cassava roots. During transportation to the processing site in a motor truck, a loss of 1.33 kg (0.71%) is observed. This loss may be due to factors like moisture loss, bruising, or damage during transit. When the cassava roots undergo peeling, there is a significant loss of 40.31 kg (21.44%), as the outer skin is removed, resulting in the removal of substantial outer layers. The washing and steeping operations do not cause any weight loss, indicating careful handling of the cassava roots during these stages. During the draining or decantation of water from the soaked roots, 10.58 kg is lost, which accounts for 5.63% of the original quantity. Draining involves removing excess water, leading to a loss of liquid content. Pressing the cassava mash to remove excess moisture results in a loss of 19.21 kg (10.22%). This step involves the extraction of liquid from the cassava. Cooking the pressed cassava roots into fufu leads to a loss of 11.79 kg (6.27%), likely caused by evaporation and the removal of impurities. This loss could be due to various factors such as evaporation during cooking, starch gelatinization, or the removal of impurities. Adding up all the observed losses, we have a total loss of 83.22 kg, which represents 44.27% of the original quantity of cassava roots (18 kg). This means that out of every 100 kg of cassava roots initially present, only approximately 55.73 kg is left after the entire fufu production process. However, it is important to note that these losses may vary with different processing techniques. The losses can be influenced by factors such as the quality or specie of the cassava roots, the proficiency of the workers, and the efficiency of the processing equipment.

The considerable overall loss of 44.27% reflects a significant reduction in the weight of the original cassava roots during the different stages of fufu production. These losses occur due to various factors, including the removal of outer layers during peeling, the elimination of water during soaking and draining, the extraction of excess moisture during pressing, and the loss of moisture and impurities during cooking. These losses are substantial and can potentially affect the profitability of fufu production. However, profitability is influenced by factors beyond the losses alone, such as market demand, production efficiency, operational costs, and pricing strategies. It is worth noting that optimizing the production process, minimizing losses through enhanced techniques and equipment, and exploring value-added products or by-products derived from the production process can help alleviate the impact of losses and potentially enhance profitability.

Table 5: Quantitative losses of cassava root along its supply chain due to transportation and unit operations of production during *fufu* processing.

Component along processing pathway	**Okitipupa area**			**Akure area**			**Ilorin area**		
	Original Cassava quantity (Kg)	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**	**Original Cassava quantity (Kg)**	**Observed loss (Kg)**	**% Loss**
Harvested cassava roots bought at the open market	188	-	-	212	-	-	194	-	-
Cassava roots brought to the processing site in a motor truck after 1-2 hr of purchase		1.33	0.71		2.42	1.14		1.80	0.93
Peeling operation		40.31	21.44		41.93	19.78		39.85	20.54
Washing		0	0		0	0		0	0
Steeping		0	0		0	0		0	0
Draining/Separation		10.58	5.63		13.04	6.15		11.35	5.85
Pressing		19.21	10.22		20.03	9.45		19.26	9.93
Cooking		11.79	6.27		12.04	5.68		11.89	6.13
Overall Total:			**44.27**			**42.20**			**43.38**

In the Akure study area, the original quantity of cassava root is 212 kg. Cassava roots are transported by truck to a processing plant one to two hours after purchase. During transportation it is observed to lose 2.42 kg (1.14%). This loss may be due to factors such as mechanical damage during transportation and natural evaporation of moisture. A peeling process is then followed, leading to a weight loss of 41.93 kg (19.78%). This loss is significant and may be due to the removal of the outer skin, which may contain dirt, debris, or damaged parts of the cassava roots. No loss is observed during washing and soaking. This indicates that cassava roots remained intact and do not undergo significant losses during these stages. Soaking the peeled cassava roots followed. A loss of 13.04 kg (6.15%) is observed during drainage or drainage after root soaking. This loss may be due to excess water being removed and some weight removed from the moist roots. Pressing is then completely done. A loss of 20.03 kg (9.45%) occurs during the pressing process. Pressing removes excess moisture and presses the cassava root to a dough-like consistency. The loss observed here may be due to root dehydration and natural compaction. Cooking the cassava roots into fufu followed. During this stage, the loss observed was 12.04 kg (5.68%). Losses during cooking may be due to evaporation of water during the heating process and the organic breakdown of certain components of cassava root.

Summing up the losses at each stage, the total loss is 89.46 kg (42.20% of the original 212 kg cassava quantity). This means that only 120.54 kg (57.80%) of the original cassava weight remains after all processing steps are completed. However, these losses affect the overall yield and profitability of cassava fufu production. Minimizing these losses is critical to improving efficiency and reducing waste along the supply chain. Therefore, process optimization, careful handling during transportation, and improved production techniques can help reduce losses and increase yields of fufu made from cassava roots. In the study area of Ilorin as seen in Table 5, it can be deduced that the original quantity of cassava roots was 194 kg. During transportation in a motor truck, a loss of 1.80 kg (0.93%) is observed, likely due to factors like moisture evaporation or physical damage. When the outer skin is peeled off during the peeling operation, a loss of 39.85 kg (20.54%) occurs, as the discarded layers result in significant waste. However, there are no losses during the washing and steeping operations, indicating their efficiency in minimizing losses. During the draining or separation of water from the soaked roots, a loss of 11.35 kg (5.85%) is observed, possibly due to soluble components or smaller pieces being carried away by water. Pressing the soaked cassava roots results in a loss of 19.26 kg (9.93%) as some cassava solids are extracted along with the expelled liquid. Finally, during the cooking process, a loss of 11.89 kg (6.13%) is observed, likely due to moisture evaporation or the removal of undesirable materials such as fibrous or woody parts.

When the losses from each step are added together, the total loss in the cassava supply chain is calculated as 43.38%. This means that out of the initial 194 kg of cassava roots, approximately 84.21 kg is lost during transportation and the various unit operations of production. This loss of weight represents a significant loss of potential revenue and food supply. It can lead to decreased profitability, lower income for farmers and processors, and increased costs due to inefficiencies in the supply chain. Considering the study area of Ilorin, producing fufu on a large scale might not be a viable business idea in terms of maximizing profits, unless measures are taken to address the issues contributing to the losses. Strategies such as reducing mechanical damage during transportation, optimizing peeling techniques to minimize waste, and refining the cooking process to minimize moisture loss can help reduce overall losses and improve the efficiency of cassava processing in Ilorin. Alternatively, producing fufu on a smaller scale can be a mitigatory solution. This approach allows for better control over waste and losses without excessive stress and strain on the production cycle. Moreover, the significant portion of lost cassava roots suggests the presence of inefficiencies in the processing operations. This highlights the need for improvements in handling, transportation, and processing techniques to minimize losses. By enhancing resource efficiency, the utilization of available cassava resources can be maximized, waste can be reduced, and both economic and environmental sustainability can be achieved.

Effect of waxing and storage period on the moisture content on selected varieties

Waxing plays a crucial role in extending the shelf life and preserving the postharvest quality of produce by modifying its internal gas and moisture composition. This protective coating can be applied through either spraying or dipping methods. After application, the wax coating dries and forms a thin film that envelops the surface of the produce, effectively creating an altered internal environment (Maina et al., 2019). The coating applied limits the amount of water leaving the produce through transpiration by reducing the number and sizes of the lenticels, thus leading to a water saturated internal environment and also regulates gaseous exchange on the surface of the fruit leading to a high CO_2 and low O_2 levels inside the fruit. The low oxygen conditions created by waxing affects physiological processes such as respiration and enzyme mediated processes such as the ethylene biosynthesis pathway. The low O_2 condition has been reported to limit activities of 1-Aminocyclopropene-1-carboxylic acid (ACC) oxidase, an enzyme that catalyzes the conversion of ACC to ethylene which aids ripening as reported by Maina et al (2019). Under low oxygen conditions, it has been observed that the enzymatic activities responsible for chlorophyll degradation and cell wall degradation are reduced.

The moisture content of harvested crops plays a significant role in determining their respiration rate. Respiration, which is a metabolic process, persists in harvested crops as they consume oxygen and release carbon dioxide. When the moisture content is higher, the respiration rates increase accordingly, causing a more rapid onset of physiological deterioration. Excessive respiration depletes the crop's energy reserves at a faster pace, resulting in a quicker decline in quality, nutritional value, and marketability. Therefore, managing and controlling the moisture content of harvested crops is crucial to mitigate the negative effects of accelerated respiration and preserve their overall post-harvest quality (Chukwu and Abdullahi, 2015). Also, the moisture content of harvested crops has a significant impact on microbial growth. Increased moisture levels provide an ideal environment for the proliferation of bacteria, fungi, and other microorganisms. These microorganisms can contribute to different types of deterioration, including rotting, mold growth, and spoilage. The presence of moisture enhances microbial activity, thereby expediting the physiological deterioration process in the crop. In addition, the moisture content of harvested crops has a significant impact on enzymatic activity. Enzymes, which are natural catalysts, play a crucial role in facilitating biochemical reactions within living organisms. Even after crops are harvested, they retain some level of enzymatic activity. However, higher moisture content can enhance this activity, triggering undesired reactions that adversely affect the quality of the crop. A notable example is enzymatic browning, a process commonly observed in fruits and vegetables, which leads to discoloration and changes in flavor. As a consequence, the market value of such crops is reduced.

However, insufficient moisture content can have detrimental effects on crops, just like excessive moisture. When there is not enough moisture, crops undergo rapid water loss or desiccation, which causes wilting, shriveling, and loss of turgidity. This dehydration process significantly reduces the quality of the crops, leading to weight loss and making them more susceptible to mechanical damage. Furthermore, the moisture content of crops plays a critical role in the growth of molds and the production of mycotoxins. Mycotoxins are harmful substances generated by specific molds, which can contaminate agricultural produce. When the moisture content is high, it creates favorable conditions for mold growth, thereby increasing the likelihood of mycotoxin production. Crops contaminated with mycotoxins present significant health risks and can result in substantial economic losses if appropriate identification and management measures are not implemented (Enujiugha et al., 2023). Therefore, in order to minimize post-harvest physiological deterioration, it is essential to control the moisture content during post-harvest handling and storage. The optimal moisture levels vary depending on the crop type, but generally, a balance must be maintained to prevent excessive moisture, which promotes microbial growth and enzymatic activity, as well as insufficient moisture, which causes dehydration and water loss. Proper drying techniques, appropriate storage conditions, and the use of moisture barriers, packaging materials, and temperature control are some strategies employed to maintain the desired moisture content and minimize physiological deterioration in harvested crops.

For a typical crop like cassava root tubers, the implementation and application of both traditional and modern methods can be employed to extend the shelf-life of the tubers. Traditional methods, which are simple and inexpensive, include underground storage, the use of wood and cardboard boxes, and polybag storage. On the other hand, modern techniques such as refrigerated cold storage, freezing, chemical treatments, and wax coating (spraying and dipping which are the most common) are also utilized to prolong the shelf-life of cassava roots. The high moisture content of cassava root makes it highly perishable, typically having a postharvest lifespan of less than 72 hours. However, transforming cassava root into various food forms and raw materials, such as flour, chips, and pellets, offers the ability to extend its shelf life significantly. This processing not only increases the longevity of cassava products but also facilitates trade and promotes their industrial utilization. By converting cassava root into processed forms, its perishability is mitigated, enabling wider distribution, storage, and application in various industries.

Figure 1 represents the effects of waxing and storage time on moisture content on selected varieties of cassava root tubers from Ondo and Kwara State in Nigeria. The varieties obtained are coded as TME-419, TMEB-593 and TMS-693. Moisture content is a crucial factor affecting the quality and shelf life of cassava root tubers. High moisture content can lead to the growth of microorganisms and mold, accelerating spoilage. On the other hand, low moisture content can result in a loss of texture and nutritional value. Therefore, maintaining an optimal moisture balance is essential for preserving the quality of cassava tubers during storage. And while moisture content is an essential quality parameter, other factors such as starch content, sugar content, and texture can also influence the overall quality of cassava tubers during storage. Future studies could examine these parameters in conjunction with moisture content to provide a more comprehensive understanding of the effects of waxing and storage on cassava quality.

The cultivars of the root tubers TME-419, TMEB-593 and TMS-693 were subjected to the same treatment of waxing, dried and stored for a duration time of 10 days. The unwaxed cultivars and waxed cultivars were compared to check for the effectiveness of waxing in the moisture content and post-harvest deterioration in the root tubers. From Figure 1, it can be deduced that there is a significant effect of waxing and how it helps to preserve the moisture content of the varieties of tuber. Although, it is important to understand that the moisture content of any produce will depend on factors such as location, season and processing methods. The moisture content ranged from 60.21% in freshly harvested tuber of TMEB-693 on day zero to 61.31% in the waxed TME-419 tubers. Moisture content reduced significantly with storage period, a similar observation was made in trifoliate yam (*Dioscorea dumetorum*) (Ezeocha and Oti, 2013). The reduction in moisture during storage can be attributed to physiological processes that the tubers underwent such as respiration, transpiration and sprouting.

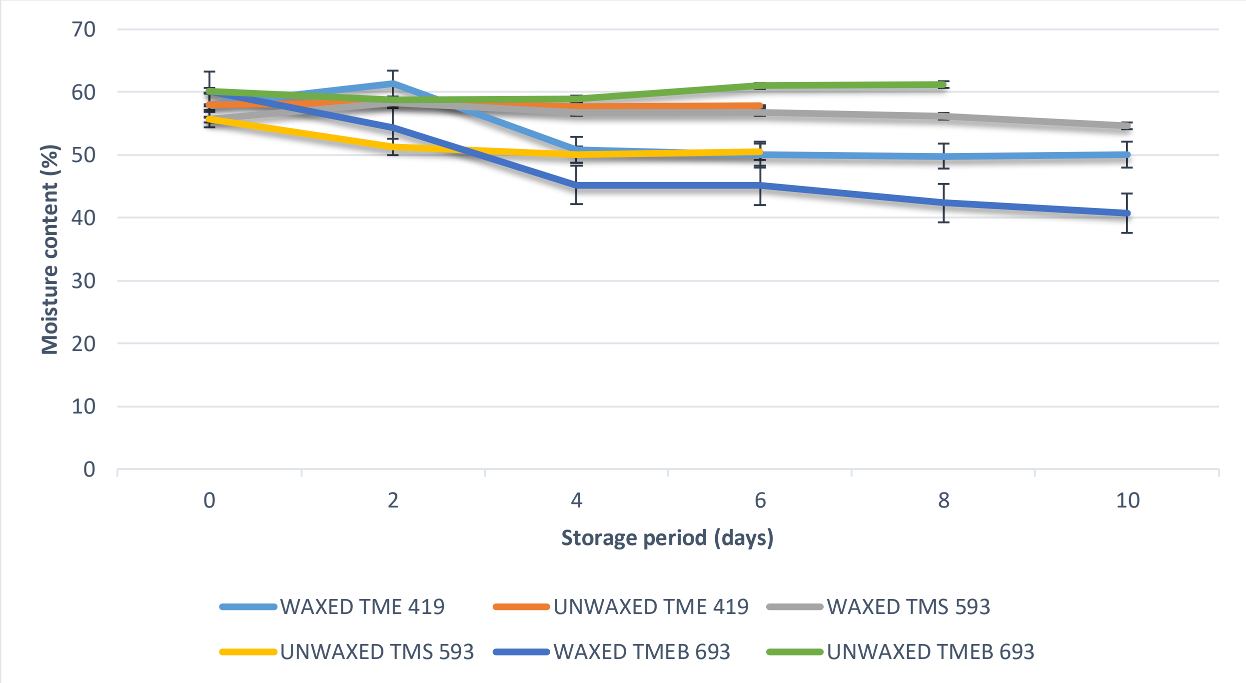

Figure 1: Effect of waxing and storage period on the moisture content of selected cassava varieties.

On day zero, both the waxed and unwaxed cultivars of TME-419, TMS-593 and TMEB-693 all maintained the same amount of moisture content, that is, 57.93%, 55.63% and 60.21% respectively. The variety or specie of cassava tuber TMEB-693 amongst others, seem to be high in moisture content maybe due to its structural matrix within the tuber system or the geographical location where it originates and environmental factors such as rainfall patterns and humidity levels can also affect the moisture content of the harvested roots. This high moisture content makes them perishable and susceptible to spoilage, so further processing or preservation methods are usually employed to extend their shelf life. On day two, the waxed cultivar TME-419 and TMS-593 had an incremental rise in moisture content (61.31% and 58.35% respectively) maybe due to the reabsorption of fat-soluble components and moisture from the environment that was able to get through the barrier of wax into the tubers to cause the increase. Also, high humidity in the environment, condensation may occur on the waxed surface, and water exposure within the storage condition may have caused the high moisture level. The unwaxed TME-419 also possessed an increased moisture content (61.31%) while both the unwaxed TMS-593 and TMEB-693 had a reduction in moisture content (51.24% and 58.75% respectively). While the unwaxed TMEB-693 had slight reduction in moisture content (58.75%). On day four, all the unwaxed cultivars had a reduction in moisture content (57.72% TME-419 and 50.02% TMS-593) due to post-harvest deterioration which had started to set in except the unwaxed TMEB-693 which instead had an absorption of a slight amount of moisture to make it slightly increase in its water level (58.92%). All the waxed cultivars, TME-419, TMS-593 and TMEB-693 exhibited a lower moisture content compared to their day two's measurements. Waxed TME-419 had 50.87%, waxed TMS-593 had 56.76% and waxed TMEB-693 had 45.22%. On day six, waxed TME-419, TMS-593 and TMEB-693 had moisture contents of 50.10%, 56.82% and 45.20% respectively. This implies that waxing the cassava root tubers helps to retain moisture. The waxed tubers consistently had higher moisture contents compared to the unwaxed tubers of the same variety. The unwaxed TME-419, TMS-593 and TMEB-693 had moisture contents of 57.80%, 50.50% and 61.00%. This implies that there is a great or rapid moisture loss with the unwaxed cultivars due to the effect of post-harvest losses. On day eight, the unwaxed TME-419 and TMS-593 had already deteriorated due to massive post-harvest losses and decay which had already set in. Only unwaxed TMEB-693 still had some moisture content of 61.20% maybe due to the type of variety it is or maybe it had the highest amount of moisture on day zero and still had much left within. On day ten, only the waxed TME-419, TMS-593 and TMEB-693 had moisture within them left while the unwaxed cultivars had already decayed and deteriorated without moisture.

It can be seen that there are variations in moisture content between the different varieties of cassava root tubers. For example, TME-419 consistently had higher moisture contents compared to TMS-593 and TMEB-693, both in the waxed and unwaxed conditions. And as the storage time increased, the moisture content of both waxed and unwaxed cassava root tubers changed. These changes varied depending on the variety and waxing condition. The waxed cassava root tubers generally exhibited slower moisture loss compared to the unwaxed tubers. This can be observed by comparing the moisture contents of waxed and unwaxed tubers at each time point. The difference in moisture content between the waxed and unwaxed tubers became more pronounced as the storage time increased. In general, the moisture content of all the cassava root tubers decreased over time. However, the rate and extent of moisture loss varied among the varieties and waxing conditions. Some tubers showed a gradual decrease, while others exhibited a more rapid decline. Notably, TME-419 in the unwaxed condition experienced a sudden drop in moisture content to 0% by day eight, while TMS-593 in the unwaxed condition reached 0% moisture content by day ten. This suggests that without proper storage conditions or waxing, these varieties can quickly lose moisture and potentially become unsuitable for consumption or processing.

The effectiveness of waxing in retaining moisture varied among the varieties. While waxing consistently helped retain moisture in TME-419 and TMS-593, it was less effective for TMEB-693. This implies that the waxing treatment may have a stronger impact on some varieties than others. The rate and pattern of moisture loss can be influenced by multiple factors, including the genetic characteristics of the cassava variety, initial moisture content, and storage conditions such as temperature and humidity. These factors can interact in complex ways, leading to the observed variations in moisture loss among the different varieties and waxing conditions. In conclusion, there is a need for waxing these cultivars immediately after harvesting because waxing can significantly help in maintaining higher moisture content in cassava root tubers during storage. However, the effectiveness of waxing may vary depending on the cassava variety. Proper storage conditions are crucial to minimize moisture loss and preserve the quality of the tubers. The findings from this study may be influenced by the specific storage conditions used. Factors such as temperature, humidity, and ventilation can all impact moisture loss rates. It would be valuable to investigate the effects of different storage conditions on the moisture content of cassava tubers, both with and without waxing, to optimize storage protocols. More also, the moisture content of cassava root tubers can also influence consumer preferences and market demand. Certain products, such as cassava flour or starch, may require specific moisture levels for processing. Understanding the moisture changes during storage can help align the production and processing practices with consumer expectations and market requirements.

Effect of waxing and storage period on the calcium content of the different cassava varieties

The calcium content of cassava tubers can vary depending on several factors, including the variety of cassava, soil conditions, environmental factors, and agricultural practices. Generally, cassava is not considered a significant source of calcium compared to other food sources like dairy products, leafy green vegetables, or fortified foods. However, cassava tubers do contain some amount of calcium. According to the United States Department of Agriculture (USDA) National Nutrient Database, the approximate calcium content in raw cassava tubers is around 16-21 milligrams per 100 grams. It's worth noting that this is a general estimation and can vary slightly based on the specific variety and growing conditions.

Figure 2 depicts the graphical relationship between waxing with storage time and the calcium contents of the selected cassava tubers TME-419, TMS-593 and TMEB-693. On day zero, unwaxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.02, 1.5 and 1.04 respectively while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.02, 1.5 and 1.04 respectively. On day two, unwaxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.02, 1.2 and 1.03 respectively while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.06, 1.5 and 1.04 respectively. On day four, unwaxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.08, 1.16 and 1.03 respectively while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.1, 1.4 and 1.07 respectively. On day six, unwaxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.03, 1.12 and 1.04 respectively while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.08, 1.4 and 1.07 respectively. On day eight, unwaxed TME-419, TMS-593 and TMEB-693 had calcium contents of 0.00, 1.08 and 0.00 respectively while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.05, 1.38 and 1.09 respectively. On day ten, unwaxed TME-419, TMS-593 and TMEB-693 all had 0.00 in calcium content while the waxed TME-419, TMS-593 and TMEB-693 had calcium contents of 1.07, 1.36 and 1.09 respectively. On day zero, both the unwaxed and waxed varieties of TME-419, TMS-593, and TMEB-693 had similar calcium contents, with values ranging from 1.02 to 1.5. This indicates that waxing did not have an immediate effect on the calcium content of the tubers.

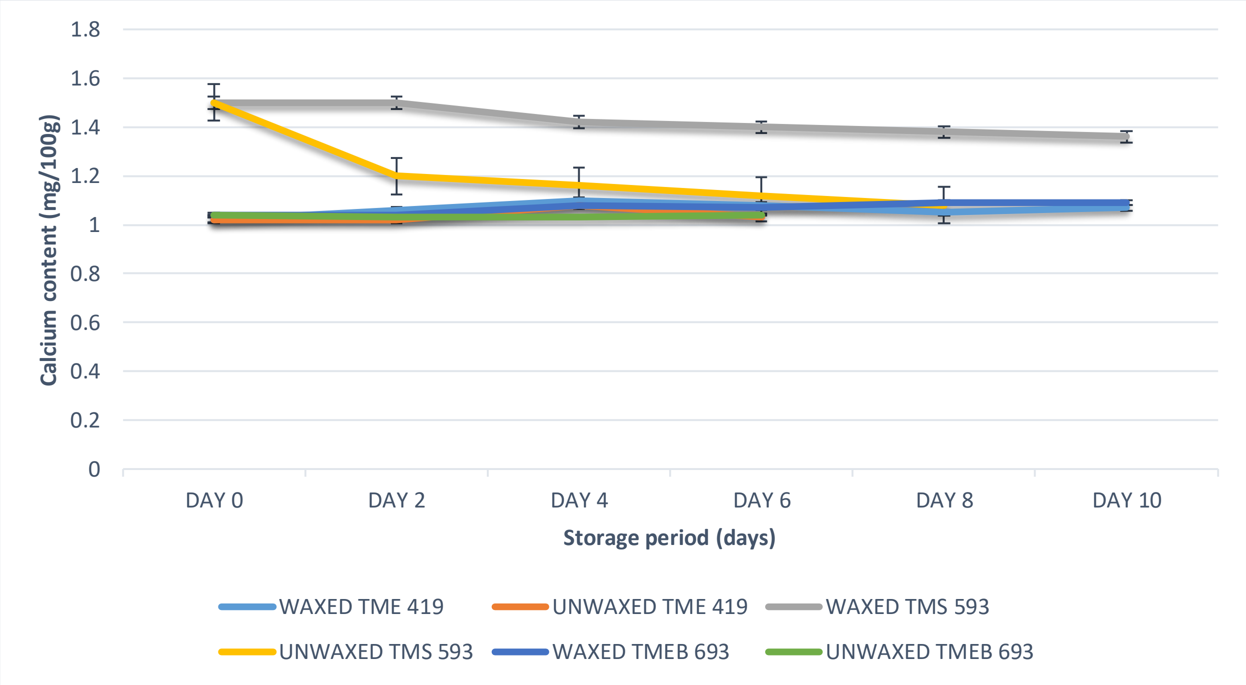

Figure 2: Effect of waxing and storage period on the calcium content of selected cassava varieties.

The waxed varieties consistently showed slightly higher calcium contents compared to the unwaxed varieties throughout the experiment. This suggests that waxing may have a positive effect on preserving the calcium content of cassava root tubers over time. On day two, the calcium contents of the waxed varieties increased slightly compared to day zero, while the unwaxed varieties showed a slight decrease. Also, on day four and day six, both the waxed and unwaxed varieties exhibited fluctuations in calcium content, but the waxed varieties generally maintained higher levels compared to the unwaxed ones. On day eight and day ten, the unwaxed varieties had significantly lower calcium contents, even reaching 0.00, while the waxed varieties still retained measurable calcium levels. This indicates that waxing helped to prevent a rapid decline in calcium content as the storage time increased. Among the three varieties tested (TME-419, TMS-593, and TMEB-693), variations in calcium content were observed. TME-419 generally had lower calcium content compared to the other two varieties, both in the unwaxed and waxed conditions. While, TMEB-693 showed relatively stable calcium content throughout the experiment, while TMS-593 exhibited some fluctuations. In conclusion, it can be deduced that waxing the cassava root tubers has a beneficial effect on preserving their calcium content during storage. Waxing appears to slow down the decline in calcium levels, especially as the storage time increases. However, also it's important to note that the calcium content of cassava root tubers can be influenced by various factors, including genetic variations among different varieties, storage conditions, and handling practices.

Effect of Waxing and Storage Period on the Cyanide Contents of Selected Cassava Varieties

Figure 3 depicts the relationship between the cyanide contents of cassava tubers TME-419, TMS-593 and TMEB-693 and the effects of storage time and waxing on the varieties of cassava tubers. On Day zero, both the waxed and unwaxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 5.69, 4.57 and 2.52 mg/kg, respectively. On day two, unwaxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 5.32, 4.37 and 2.15 mg/kg, respectively while the waxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 5.47, 4.61 and 2.27 mg/kg, respectively. On day four, unwaxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.67, 4.72 and 1.82 mg/kg, respectively while the waxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.947, 4.64 and 1.18 mg/kg, respectively. On day six, unwaxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.75, 4.7 and 2.4 mg/kg, respectively while the waxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.82, 4.63 and 2.02 mg/kg, respectively. On day eight, unwaxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 0.00, 0.00 and 1.19 mg/kg, respectively while the waxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.548, 4.28 and 1.16 mg/kg, respectively. On day ten, unwaxed TME-419, TMS-593 and TMEB-693 all had zero cyanide content while the waxed TME-419, TMS-593 and TMEB-693 had cyanide contents of 4.02, 4.08 and 1.11 mg/kg, respectively.

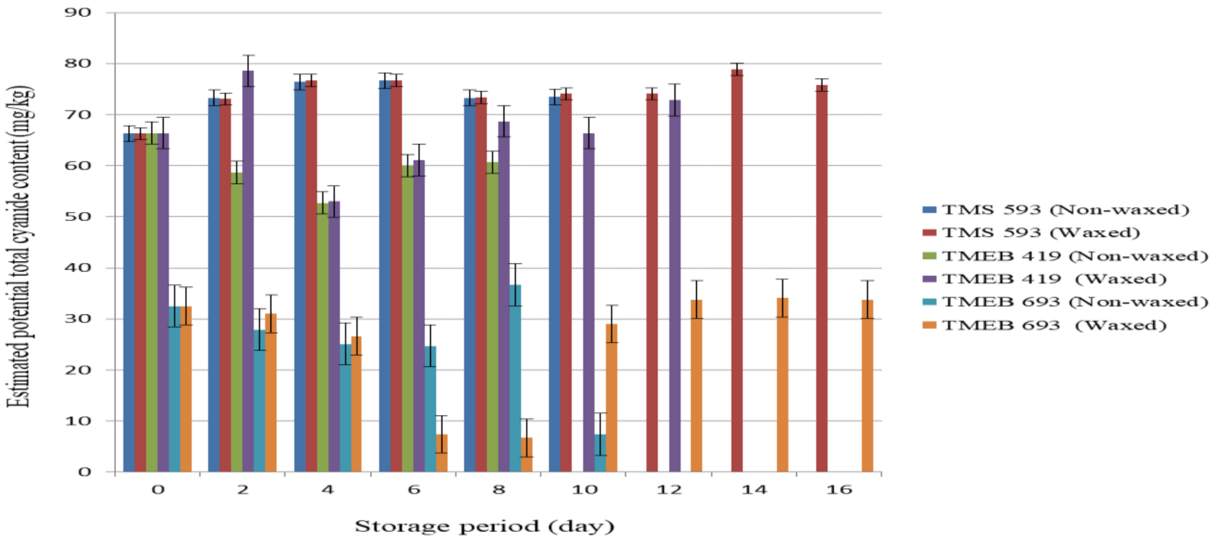

Figure 3: Estimated potential total cyanide content of waxed and non-waxed cassava roots during storage in ambient conditions.

All the varieties tested in this study had cyanide contents both in the fresh roots and waxed roots. On day zero, both the unwaxed and waxed variants of cassava exhibited comparable levels of cyanide. This indicates that the application of wax alone does not have an immediate effect on cyanide concentrations in cassava tubers. As the duration of storage increased, both the unwaxed and waxed cassava tubers generally demonstrated a decrease in cyanide content. This pattern suggests that the cyanide content in cassava naturally declines during storage, regardless of whether the tubers are waxed or not. According to Anorue *et al*. (2021), certain foods like cassava (*Manihot esculenta* Crantz) contain cyanogenic glycosides, which are phytotoxins. If not processed properly, these toxins can make the food harmful for human consumption. Throughout much of Africa, cassava root tubers are used as a staple food due to their high carbohydrate content. However, some cassava products can contain dangerous levels of cyanoglycosides, posing a serious threat to human health. In order to maximize production and profit, producers often employ faster and shorter processing techniques, which can result in higher residual levels of cyanoglycosides in the final products. Studies have indicated that the consumption of inadequately processed cassava products may lead to the oxidation of human hemoglobin (Hb) (Anorue *et al.*, 2021). Cyanogenic glycosides are CN− compounds present in cassava edible tuberous roots that is commonly processed into flour. However, this cyanogenic glycoside, which can be extremely toxic and cause cyanide poisoning if not adequately detoxified. To remove the toxins, cassava typically undergoes a detoxification process involving soaking, drying, and scraping before it can be safely consumed. Although cases of acute cyanide poisoning from cassava consumption are seldom reported (Alitubeera et al., 2019).

Upon comparing the cyanide levels of unwaxed and waxed cassava tubers at each time interval, it becomes apparent that the waxed tubers consistently exhibited slightly higher cyanide concentrations. This suggests that waxing may have a minor influence on preserving the cyanide content in cassava tubers during storage, although the difference is relatively insignificant. Among the selected varieties (TME-419, TMS-593, and TMEB-693), there were variations in initial cyanide levels and their changes over time. For instance, TME-419 consistently displayed the highest cyanide content among the varieties, while TMEB-693 had the lowest cyanide content. Furthermore, as the storage period increased, cyanide content decreased in all varieties, both in the waxed and unwaxed tubers. This decline in cyanide content is likely due to natural enzymatic processes that take place during storage, leading to the breakdown of cyanogenic glucosides, the compounds responsible for cyanide formation in cassava. It is noteworthy that on day eight and day ten, the unwaxed TME-419 and TMS-593 varieties exhibited zero cyanide content. This suggests that prolonged storage can effectively reduce cyanide levels to safe or negligible amounts, rendering the tubers suitable for consumption.

Overall, the data indicates that waxing may have a slight impact on preserving cyanide levels in cassava tubers during storage, but the natural enzymatic processes that occur during storage play a more significant role in reducing cyanide concentrations. It is important to recognize that while cyanide content decreases over time, the specific safety threshold for cyanide in cassava depends on various factors such as local regulations and cultural practices. Therefore, it is crucial to follow appropriate processing methods to ensure the safety of consuming cassava. On the other hand, the exposure of the roots results into loss of the volatile cyanide, much as such exposure increases the physiological deterioration of the root. Given the role of hydrogen cyanide as a stress related secondary metabolite, it is important to note that losses in cyanide will increase the propensity of the root to deteriorate. Thus, minimal reductions in cyanide during storage would be desired for improved shelf life. However, this is not ideal given the serious safety and health impacts of cyanide on consumers. Such safety and health impacts have implications on cassava product safety and calls for implementation of safety strategies in marketing of fresh cassava products (Nuwamanya *et al.*, 2019).

4. Conclusion

The findings of this study showed that waxing technology can be used to reduce postharvest losses in cassava processing system as most processors do not have viable alternative means of preservation. In addition, waxing technology was found to be efficient enough to prevent deterioration. During peeling the wax on the cassava can be carefully removed from the outer covering (peels) of the cassava tuber, thereby allowing the processors to reuse. The results showed that unwaxed cassava roots deteriorated between 4 and 6 days, while the waxed roots lasted up to 10 days before showing signs of deterioration. Different cassava-based products exhibited diverse levels of losses during processing which are gari (37- 44%), pupuru (38 - 40%), and fufu (42- 44%). The findings of this study showed that waxing technology can be used to reduce postharvest losses in cassava processing, especially as most processors do not have alternative means of preservation.

Conflict of Interest

Authors declare no conflicts of interest.

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