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Research Article

Evaluating the Effects of Drying Temperatures on the Nutritional and Bioactive Quality of Ackee Aril Apples

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ABSTRACT

This study examines the effects of varying drying temperatures on the bioactive and nutritional characteristics of ackee aril apples (Blighia sapida), The study showed how drying temperatures affect ackee aril apples' nutritional and bioactive qualities, emphasizing the fruit's potential as a useful dietary ingredient with both financial and health advantages. The harvested fresh ackee aril apples were cleaned, dried in an oven at different temperatures (40°C, 50°C, 60°C, 65°C, and 70°C), and then dried under the sun. Proximate techniques to examined nutritional qualities such as moisture, fat, protein, ash, fiber, and carbohydrate content. Vitamin C, flavonoid content, and total phenolic content were among the ascertained bioactive quality characteristics. The lowest moisture content of 2.997% was reached at 70°C which is safer for storage. Higher drying temperatures resulted in a lower moisture content and a faster reduction in moisture. Significant differences in nutritional components were found during drying, including a rise in crude fiber and protein content and a decrease in ash content. To evaluate the energy potential, metabolic energy was computed as the drying temperature rose and the amount of carbohydrates increased. Dried ackee aril apples may have potential as a nutraceutical because bioactive quality parameters like flavonoids, total phenolic content, and vitamin C rise with drying temperature. The findings highlight the value of drying as a preservation method to increase this perishable fruit's shelf life.

Keywords: *Ackee aril, Drying temperature, Nutritional quality, Bioactive properties, Drying, Perishable fruit.*

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INTRODUCTION

Crops can be classified into food and cash crops, with the latter serving both commercial and consumption purposes (Sawicka, 2019). Agriculture is vital to Nigeria's economy, with over 70% of the country's extensive land suitable for cultivation (Maxwell, 2018). While Nigeria has a growing population, agriculture's contribution to GDP has decreased over the years due to various factors, leading to food insecurity (Ekué *et al.*, 2010; Otaha, 2013; Dossou *et al.*, 2014a). Diversifying food sources, such as conserving indigenous crops like ackee, is crucial for addressing this challenge.

Ackee aril apples, a West African tree crop and Jamaica's national fruit hold immense economic and nutritional potential. The ackee tree belongs to the *Sapindaceae* family and thrives in well-drained soil (Sanford *et al.*, 2018; Kakpo *et al.*, 2020). It produces small, hermaphroditic flowers during warm months and can reach heights of 7-25 m. The fruit changes color as it ripens and splits into three sections, revealing the arillus/aril, a creamy fleshy part with a nutty flavor. Aril is a versatile food that can be eaten raw, dry, fried, roasted, or blended into a sauce. However, caution is advised as the raphe (Figure 1), a thin lining membrane, should be removed before consumption due to its hypoglycin A content (Anupama and Sunilkumar, 2019).

The ackee fruit contains two amino acid components responsible for the toxic hypoglycaemic syndrome, also known as Jamaican vomiting sickness (Kakpo *et al.*, 2020). They are called hypoglycin A and B, and according to Sanford *et al.* (2018), hypoglycin A is more water soluble and hazardous than hypoglycin B. Symptoms of toxicity, including nausea, vomiting, and hypoglycemia, occur within 6-48 hours of ingestion, which can be fatal, particularly in young children (Aubry, 2012; Kakpo *et al.*, 2020). Early administration of sugar and glucose is recommended to relieve symptoms. The cooking of the arils of unripe ackee fruit does not reduce toxicity, but cooking ripe arils eliminates toxicity by leaching hypoglycin A (Emanuel and Benkeblia, 2011). Research has shown that hypoglycin A transfers from the arils to the seeds as the fruit matures, reducing its toxicity to about one-tenth of the original level. Additionally, when the pods of the fruit open at full maturity, sunlight dispels toxicity (Emanuel and Benkeblia, 2011).

Drying is a crucial preservation method to extend the shelf life of food goods. To determine the effects of varying drying temperatures on ackee aril apples' nutritional value and bioactive characteristics, we concentrated on Ackee aril apples (*Blighia sapida*). Canned ackee arils have generated significant revenue in Jamaica, highlighting the economic potential of this fruit (Emanuel and Benkeblia, 2011; JIS, 2018). Nevertheless, the ackee's status as a highly perishable seasonal fruit in its land of origin presents a challenge. This study specifically focuses on how drying affects the nutritional quality of the ackee aril apple, excluding other parts of the ackee fruit. The study involves sun drying and oven drying at varying temperatures (40°C, 50°C, 60°C, 65°C, and 70°C) to enhance preservation.

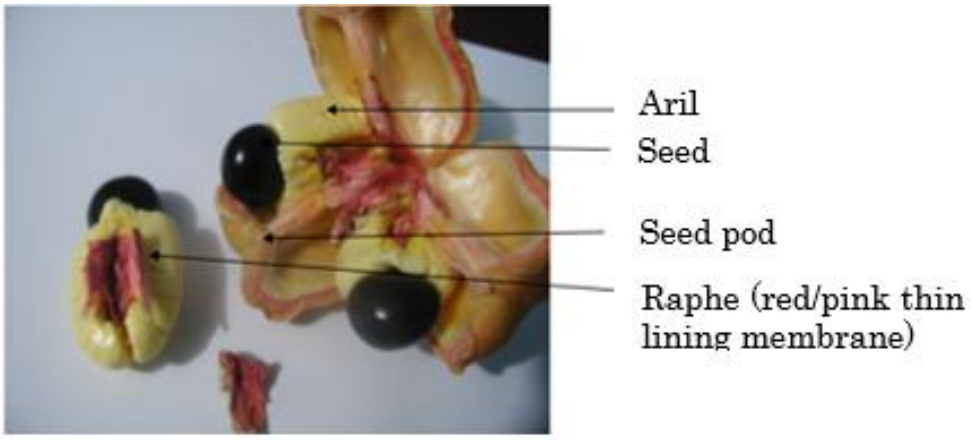

Figure 1. *Parts of the Ackee Fruit* (Wray *et al.*, 2020)

MATERIALS and METHODS

Materials

The fresh ackee aril apple used in this study was subjected to drying using the following materials and equipment:

i. Oven dryer (DHG-9053A) with a fixed air velocity of 1.4 m s^{-1}. The oven operates at a voltage of 220V and 50Hz.
ii. Electronic weighing scale (Golden-Mettler, model-20002) with a measurement precision of ±0.01 g and a maximum capacity of 2000 g.
iii. Trays wrapped with foil paper for arranging the samples before placing them in the oven and sun.

Raw Material and Sample Preparation:

Fresh and mature ackee aril apple fruits were harvested from a tree in Akure, Ondo State, Nigeria. To get rid of damaged fruits, ripe ackee apples were sorted, washed, and cleaned. The seeds and raphe were manually removed, and the samples were grouped and placed in trays for further processing (Figure 2a and 2b).

Figure 2a. *Freshly harvested acked apple fruits.* ***Figure 2b.*** *Clenaed ackee aril apple.*

Experimental Site

The research was conducted in the Crop Processing Laboratory, located within the Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure (FUTA), Ondo State, Nigeria.

Methods

The methods employed in this study are described as follows:

Drying:

The Ackee aril apples were subjected to drying using two methods:

a. Sun Drying: Ackee aril apples were spread out in the sun until a constant weight was achieved.
b. Oven Drying: The drying was conducted in an oven dryer (DHG-9053A) with a fixed air velocity of 1.4 m s^{-1}. The oven operates at a voltage of 220V and 50Hz. Samples were arranged on trays wrapped with foil paper and placed in the oven dryer (at various temperatures of 40, 50, 60, 65, and 70°C). The drying process was continued until a constant weight was achieved.

Nutritional Quality:

The nutritional quality of the ackee aril fruit was determined, including moisture content, fat, protein, ash, fiber, and carbohydrate content. The following standard methods were used for analysis:

a. Moisture Content: Analyzed using the standard AOAC (2012) method. It involved weighing an empty evaporating dish (W1), adding 10g of the sample to the dish (W2), drying the sample at 105°C, and calculating the moisture content using Equation 1.

$$\%MC = \frac{W2 - W3}{W2 - W1} 100 \quad (1)$$

Where W_1 is the weight of the empty evaporating dish;
W_2 is the weight of the sample + evaporating dish
W_3 is weight of sample + evaporating dish after drying at 105˚C.

b. Crude Fat Content: Determined by saponifying the extracted fat content of the sample and then analyzed by gas chromatography described by Olagunju and Nwachukwu, (2019).
c. Protein Content: Measured by the micro-Kjeldahl method, where the percentage nitrogen content was calculated and multiplied by a factor of 6.25 to determine the protein content (Equation 2).

$$\%Protein = \frac{N.F \times M \times V_1 \times T \times PF \times 100}{V_2 \times W} \quad (2)$$

Where N.F *is* the nitrogen factor (0.014); M is the morality of HCl (0.01);
V_1 is the final volume of digest (50 ml); V_2 is the volume of digest used (10 ml);
Tis the titre volume of distillate; W is the Weight of sample used;

PF is the protein multiplication factor (6.25)

d. Ash Content: Ash content was determined by ashing the sample in a muffle furnace at 600°C. The final weight of the sample was taken, and the percentage ash content was calculated using Equation 3 stated by Oguntola *et al.* (2019):

$$\%Ash = \frac{(weight of empty crucible + ash) - weight of empty crucible}{Weight\ of\ sample\ taken} \times 100 \quad (3)$$

e. Crude Fiber Content: Crude fiber was obtained through hydrolysis and filtration methods. The percentage crude fibre was calculated using the Equation 4 as stated by Oparaku *et al.* (2010):

$$\%crude fibre = \frac{loss \in weight after drying}{weight of sample} \times 100 \quad (4)$$

f. Carbohydrate Content: Calculated by subtracting the sum of ash, protein, fat, moisture, and crude fiber from 100, using Equation 5 as stated by Olabinjo and Adeniyan (2020) and Oparaku *et al.* (2010):

$$\%Carbohydrate = 100 - (\%ash + \%protein + \%moisture + \%crude fibre) \quad (5)$$

g. Calculated Metabolic Energy: it was estimated using Equation 6 stated by Akalu and Geleta (2019). The metabolic energy is measured in kcal 100 g^{-1}.

$$CME = (9 \times crude fat) + (4 \times protein content) + (4 \times carbohydrate content) \quad (6)$$

Bioactive Quality:

Bioactive quality parameters, including total phenolic content, vitamin C, and flavonoid content, were determined using relevant methods.

a. Total Phenolic Content (TPC): Analyzed using the Folin-Ciocalteu reagent reducing substance method. Gallic acid corrosive was used as standard and results were expressed as Gallic acid equivalents (mg GAE) (Batista *et al.*, 2016).
b. Vitamin C: It was determined through titration with 2,6-dichlorophenol indophenol using the standard AOAC (2005) method.
c. Flavonoid Content: Calculated using the method described by Mudoi and Das (2019).

RESULTS AND DISCUSSION

Effect of temperature on the moisture content of the ackee aril apple

Figure 3 demonstrates that higher drying air temperatures lead to shorter drying times and a more rapid decrease in moisture content. The moisture's movement from the center of the biomaterial to the surface can be attributed to its diffusion, which explains this pattern (Nguyen *et al.*, 2019).

Before drying, the ackee aril apple's initial moisture content was approximately 54.814% wet basis (wb). At drying temperatures of 70°C, 60°C, 50°C, 40°C, and open sun drying, respectively, the moisture content decreased to 2.997%, 4.530%, 7.097%, 7.520%, and 7.725%. When the drying process started, the moisture movement was shown to decrease gradually; however, when the temperature rose during drying, it accelerated until it reached the equilibrium moisture content (EMC).

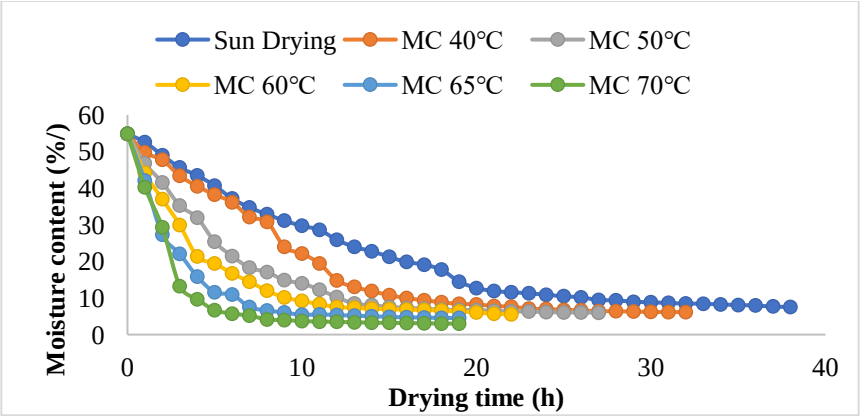

Figure 3. *Moisture content against drying time (hour) at different drying temperature.*

Effect of temperature on the nutritional composition of ackee aril apple

Proximate analysis revealed significant variations in nutritional components during drying. Sun-dried and oven-dried ackee aril apple at 40°C showed similar results. The different impact of drying temperatures on the retention of nutritional components can be attributed to their varying stabilities (Joshi *et al.*, 2011).

Ash Content

Ash content reflects mineral presence, quality, and safety. Increasing oven drying temperature led to decreased ash content from 5.010% at 40°C to 2.856 % at 70°C. Compared to other foods such as palmyra palm, cashew kernels, taro, and yam, ackee aril apple contains a notable amount of minerals, making it a valuable dietary component (Abe-Inge *et al.*, 2018; Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Moisture Content

Initial moisture content was 54.814%, highlighting its perishability. The lowest moisture content of 2.997% was achieved at 70°C and lowered than the moisture content reported by Dossou *et al.*, (2014b) with 4.83% which can have negative effect on nutritional and bioactive composition of the sample. Compared to taro, yam, and cashew kernels oven-dried at 50-70°C, ackee aril apple displayed higher moisture content (Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Crude Fat Content

Ackee aril apple is rich in fat and suitable for commercial soap and oil production. Dietary fat promotes fat-soluble vitamin absorption (Dossou *et al.*, 2014b; Oyeleke *et al.*, 2013). Drying temperatures decreased fat content, with the lowest fat content

(7.910%) observed at 50°C oven drying temperature. Ackee aril apples were found to contain more crude fat than taro (0.77% - 1.26%) and yam (0.71% - 1.30%) oven-dried at 50-70°C (Akalu and Geleta, 2019). The high-fat content in ackee aril apples with Oleic acid can contribute to reducing the risk of prostate cancer when incorporated into a diet (Goldson *et al.*, 2014).

Crude Fibre Content

Ackee aril apples have been identified as a rich source of dietary fibre, which is beneficial for digestion and offers numerous health advantages. These include lowering cholesterol levels and reducing the risk of cardiovascular diseases, obesity, colon diseases, and type 2 diabetes (Anupama and Sunilkumar, 2019; Ouattara *et al.*, 2010).

The study results indicated a notable rise in the crude fibre content in dried ackee aril apples as compared to their fresh counterparts. The process of oven drying at 60°C led to the maximum percentage increase (31.997%) in crude fibre content, suggesting that the drying process significantly enhances the fibre content. When compared to other food items such as cashew kernels, yam, and taro, the crude fibre content of ackee aril apples was found to be considerably higher (Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Protein Content

The protein content of ackee aril apple, initially low at 5.335%, can be increased through drying (Anupama and Sunilkumar, 2019; Dossou *et al.*, 2014b; Ouattara *et al.*, 2010). Sun drying yields the highest protein content (23.068%), while oven drying at 50℃ gives the lowest (10.987%). A balance of protein content (22.797%) and safe moisture levels is achieved at 60℃. This method produces higher protein content than in cashew kernels, taro, and yam dried similarly (Olalekan-Adeniran and Ogunwolu, 2018).

Carbohydrate content

An increase in drying temperature led to a rise in carbohydrate content. Samples dried at 70℃ had the highest carbohydrate value of 43.022%, a 72.93% increase from fresh ones. The ackee aril apple had less carbohydrate content than taro and yam. However, it's still a good source of carbohydrates, which are crucial for energy production (Akalu and Geleta, 2019).

Calculated metabolic energy (CME)

Fresh ackee aril apples had the lowest metabolic energy (213.365 kcal 100 g^{-1}), while those dried at 70°C had the highest (341.528 kcal 100 g^{-1}), attributed to their high moisture content (Abe-Inge *et al.*, 2018). These values differed from those reported by Dossou *et al.* (2014b). Among comparable foods, ackee aril apples exceeded the metabolic energy of palmyra palm but were lower than cashew kernels (Abe-Inge *et al.*, 2018; Olalekan-Adeniran and Ogunwolu, 2018; Akalu and Geleta, 2019). Ackee aril apples exhibit high metabolic energy potential.

Table 1. Result of proximate analysis of ackee aril apple.

S/N	Parameters (%)	Fresh Samples	Oven Dried Samples				
			70°C	60°C	50°C	40°C	Sun Dried
1	Ash Content	1.737	2.856	4.566	5.240	5.010	4.565
2	Moisture Content	54.814	2.997	4.530	7.097	7.520	7.725
3	Crude Fat Content	16.161	13.108	13.137	7.910	12.546	13.546
4	Crude Fibre Content	10.309	25.150	31.997	30.497	28.329	25.802
5	Protein Content	5.335	12.867	22.797	10.987	20.816	23.068
6	Carbohydrate Content	11.644	43.022	22.973	38.269	25.744	25.294
7	Calculated Metabolic Energy (kcal 100 g^{-1})	213.365	341.528	301.313	268.214	299.154	315.362

Effect of temperature on the bioactive composition of ackee aril apple

The presence of natural antioxidants in ackee aril apple, including flavonoids, total phenolic compounds, and ascorbic acid, holds significant implications for health maintenance and the prevention of chronic and degenerative diseases (Anupama and Sunilkumar, 2019). Previous research has underscored the medicinal and disease-preventive potential of bioactive and nutritional components in food materials (Anupama and Sunilkumar, 2019). Notably, oven-dried ackee aril apple exhibited higher concentrations of total phenols, vitamin C, and flavonoids than the fresh counterpart, suggesting its suitability as a nutraceutical (Table 2).

Flavonoids

Drying air temperatures significantly increased the flavonoid content in ackee aril apples. Sun drying yielded the highest flavonoid content at approximately 23.588 mg 100 g^{-1}, while oven-drying at 50°C resulted in the lowest at 12.989 mg 100 g^{-1}. Interestingly, drying at 70°C for 19 hours and at 60°C for 22 hours led to nearly identical flavonoid content, approximately 19.801 mg 100 g^{-1}, representing a substantial increase from the fresh state. This fluctuation may be attributed to operational factors during sample weight measurements. Flavonoids offer various bioactive benefits, including antiviral, antibacterial, anti-inflammatory, cardio-protective, antidiabetic, anticancer, anti-aging properties, and the ability to modulate the body's response to allergies, viruses, and carcinogens (Wang *et al.*, 2018).

Total Phenolic Content

Fresh ackee aril apples possessed a total phenolic content of approximately 11.545 mg 100 g^{-1}, signifying its rich source of phenolic compounds, known for their potential in reducing blood pressure and offering anticancer and antibacterial properties, as well as the ability to adsorb and neutralize free radicals (Anupama and Sunilkumar, 2019). Anupama and Sunilkumar (2019) recommended a daily intake of 100g of ackee aril apple to meet the body's daily phenolic requirement. Notably, higher temperature significantly affected total phenolic content positively, with highest and lowest values observed at 70°C (26.185 mg 100 g^{-1}) and 40°C (15.993 mg 100 g^{-1}). Samples dried at higher temperature exhibited higher total phenolic but 50°C exhibited higher values (22.055 mg 100 g-1) than those dried at 60°C (21.383 mg 100

g^{-1}), which could be influenced by external factors. While the total phenolic content in this study was lower than that of red apple slices (71.26 mg 100 g^{-1}) oven-dried at 70°C, as reported by Joshi *et al.* (2011), it exceeded the value for fresh ackee aril apple (9.9 mg 100 g^{-1}) reported by Anupama and Sunilkumar (2019). Notably, the results revealed a direct relationship between drying temperature and total phenolic content.

Vitamin C

Fresh ackee aril apple contained approximately 3.887 mg 100 g^{-1} of vitamin C, which increased by about 79% during open-sun drying (18.536 mg 100 g^{-1}) over 38 hours. Samples subjected to oven drying at different temperatures displayed higher vitamin C levels than the fresh sample. Specifically, ackee aril apple dried at 70°C, 60°C, 50°C, and 40°C exhibited vitamin C contents of 12.258 mg 100 g^{-1}, 17.750 mg 100 g^{-1}, 14.152 mg 100 g^{-1}, and 13.038 mg 100 g^{-1}, respectively. Although the vitamin C content reported in this study was lower than that of red apple slices (78.14 mg 100 g^{-1}) oven-dried at 70°C according to Joshi *et al.* (2011), it was notably higher than the value for fresh ackee aril apple (1.15 mg g^{-1}) reported by Anupama and Sunilkumar (2019). Vitamin C is crucial in stabilizing folate and aiding metabolism, such as tyrosine metabolism. Ackee aril apple, with its considerable vitamin C content, can serve as an antioxidant, commonly called ascorbic acid.

Table 2. *Bioactive Composition of Ackee Aril Apple.*

S/N	Parameters (mg 100 g^{-1})	Fresh Samples	Oven Dried Samples				Open Sun
			70°C	60°C	50°C	40°C	
1	Vitamin C	3.887	12.258	17.750	14.152	13.038	18.536
2	Flavonoids	9.542	19.801	19.801	12.989	19.241	23.588
3	TPC	11.545	26.185	21.383	22.055	15.993	20.661

CONCLUSION

The research findings on the impact of different drying temperatures on ackee aril apples (*Blighia sapida*) provide valuable insights into this tropical fruit's potential for both economic and nutritional purposes. Higher temperatures during the drying process significantly reduced the moisture content, which decreased the chance of spoiling and increased shelf life. When they were dried, Ackee aril apples showed significant differences in their nutritional composition. A decrease in ash content indicates reduced mineral content. On the other hand, there was a noticeable rise in the amount of protein and crude fiber. Improved digestion and a lower risk of multiple illnesses are just two of the many health advantages of dietary fiber. The carbohydrate content of dried ackee aril apples also increased with drying temperature, making them a potential energy source. Ackee aril apples displayed a rich fat content, making them suitable for commercial soap and oil production. High-fat content can also aid in the absorption of fat-soluble vitamins. Drying at elevated temperatures increased bioactive properties. Flavonoids, total phenolic content, and vitamin C were all enhanced. Ackee aril apples, especially those dried at higher

temperatures, showed significant potential as a source of natural antioxidants. These bioactive compounds have various health benefits, including antiviral, antibacterial, anti-inflammatory, cardio-protective, antidiabetic, anticancer, and anti-aging properties. The research findings highlight the economic potential of ackee aril apples, particularly in regions like Jamaica, where canned ackee arils have generated significant revenue. The study underscores the fruit's potential as a nutraceutical, providing economic and health benefits. In conclusion, drying ackee aril apples at different temperatures extends their shelf life and enhances their nutritional and bioactive properties.

DECLARATION OF COMPETING INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors confirm contribution to the papers as follows:
Oyebola Odunayo Olabinjo: Methodology, conceptualization, formal analysis, data curation, validation, Editing.
Mercy Omowunmi Sama: Investigation, Writing (original draft, Review, Visualization).

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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