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Research Article

Development of an Improved Steamer for Optimum Retention of Carotenoids in Attiéké Produced from Biofortified Cassava (*Manihot esculenta* Crantz) Roots

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Attiéké, made from biofortified (yellow) cassava genotypes, requires a new cooking method to minimize carotenoid degradation during processing. Thus, this research is aimed at designing and building a more efficient steamer to produce high-quality attiéké from biofortified cassava roots. Using three improved biofortified cassava genotypes (IBA141092, IBA070593, and IBA011368) obtained from IITA research farms, attiéké samples were produced using traditional and developed steamers. The results show that the developed steamer outperformed the traditional steamer; it was 1.5 times faster, used less fuel (2.6 times less), and had higher true carotenoid retention. The developed steamer genotype IBA070593 had the highest true retention of 90.4 percent, while the traditional steamer genotype IBA0141092 had the lowest carotenoid retention of 61.9 percent and the highest in the developed steamer (62.4 percent). When compared to the traditional steamer, the developed steamer had better cooking performance and a more extraordinary ability to retain carotenoids. Thus, the developed steamer is recommended for attiéké processors due to its improved cooking performance, and using this steamer to produce attiéké from biofortified cassava will help to alleviate vitamin A deficiency among attiéké consumers.

1. Introduction

When cassava is dried to a powdery extract called tapioca, it can be made into various products, including garri, which is fried and granular, and attiéké, which is steam-cooked. Attiéké is a traditional dish from Côte d'Ivoire. Three ethnic groups (Adjoukrou, Alladjan, and Ebrie) prepared massive amounts of attiéké for supply to Abidjan [1]. Attiéké preparation is becoming more popular in other parts of Côte d'Ivoire, as well as other countries in West Africa [2–4] and Europe. There is

(a) (b)

Figure 1: Traditional attiéké steaming method using (a) firewood and (b) coal.

no recent data on attiéké consumption. However, Aboua et al. [5] estimated attiéké consumption to be between 28 000 and 34 000 tons per year, the equivalent of 40 000-50 000 tons of fresh cassava by small-scale channels, resulting in changes in production from family to commercial type [6, 7]. Gelatinization of granulated starch is a significant change that occurs during the steaming process and affects the texture and color of foods, particularly attiéké, from start to finish. A nonbiofortified cassava root without vitamin A has always been used to make attiéké. In collaboration with national partners, the International Institute of Tropical Agriculture (IITA) addressed the significant public health problem of vitamin A deficiency (VAD) by developing biofortified cassava genotypes with the biointroduction of carotenoids in the roots in the form of β-carotene [8]. On the other hand, using high heat during the processing of biofortified roots has been shown in studies to degrade and reduce the quality and quantity of carotenoids in cassava-based products [9]. As a result, attiéké made with biofortified (yellow) cassava genotypes will require a new cooking method to prevent vitamin degrading or reduction during processing. This study looks into steaming, a very gentle cooking method to prevent vitamin loss during cooking. The healthiest cooking method is steaming. It is also environmentally friendly [10]. Fang and Chinnan [11] developed a kinetics model for cowpea starch gelatinization and discovered that water diffusion and time during steaming influence starch gelatinization. The same is true for cassava starch gelatinization. Stapley and Landman et al. [12] simulated whole wheat grain steaming. They discovered that the best conditions for steaming are when heat is efficiently conducted away from the grains through contact with the metal cooker's walls rather than contact with other grains alone.

Furthermore, researchers have worked to improve the production and storage of attiéké, as well as its nutritional value and sensory properties [4, 13, 14]. Several types of research on steaming are being considered, including how to improve its properties and the effects on the quality/preference of attiéké production in Côte d'Ivoire. The consumption of attiéké is becoming more popular. The traditional method of processing attiéké must be upgraded to meet the increased demand. The traditional steaming method has three fundamental flaws: it is time-consuming, it is labor-intensive, and the product's quality attributes vary greatly [15]. Little research has been done into developing a pilot steam cooker to test carotenoid retention in yellow (biofortified) cassava products. The production of attiéké from biofortified cassava will benefit consumers' health. Studies have shown processing to degrade and reduce the quality of carotenoids in cassava-based products [16, 17]. This investigation is aimed at creating a steam cooker for maximum carotenoid retention in biofortified cassava products like attiéké.

Creating an energy-efficient, cost-effective, and simple steaming facility would help reduce the labor associated with the traditional cooking of high-quality attiéké. This paper is aimed at designing and testing a steamer powered by a renewable energy source using locally available materials. The goal is to optimize the steam cooker for biofortified cassava roots by improving conventional steam cookers found in Côte d'Ivoire (Figure 1).

2. Materials and Method

2.1. Design of the Steam Cooker and Dimension Calculations. An interactive field trip was taken to processing centers in Côte d'Ivoire to understand the processing techniques and streaming methods better. The data gathered during the trip was compared to what was available in the literature. Based on the observations made during the trip, a cylindrical design was chosen for the new steamer (Figure 2). The steam cooker was designed and built in this manner. Figures 3 and 4 show the steamer's dimensions and an exploded view.

The cooking time of the steamer, production cost, material availability, and carotenoid retention in attiéké were all studied.

The steamer's design analysis was carried out based on the necessary parameters for functionality, the strength of the materials, and the careful selection of the various components. Each compartment of the steam cooker was measured with the actual calculations based on the following assumptions: the cooking, water, and heating chambers are cylindrical. The shape was assumed to be cylindrical as most cooking utensils are of that kind of shape to make it easy to handle. The diameter was assumed to be around 30 cm

Figure 2: Pictorial view of the developed steamer/cooker.

to 80 cm for easy handling by both human hands. The total height of the cooker was to take care of the reach of the average human body for handling and watching/observing inside. Other assumptions were as follows:

(i) Unlike traditional cookers, the cooker should be able to steamed-cook the attiéké quickly

(ii) The cooker should be made with readily available materials

(iii) The cooker should be able to retain carotenoids in attiéké better than the traditional cookers

(iv) The cost of the cooker should be affordable to the processors

All these were used as guides during the calculations.

2.1.1. Steamer Volumes. The pot shape and volume of the cooking pot, water pot, and heating chamber were among the assumptions. The volume was calculated using the shape volume V formula as shown below:

$$V = \pi r^2 h, \tag{1}$$

where r is the radius of the component (diameter/2) and h is the height of each component, respectively. In cases where the component must be filled to two-thirds, only adjustments were made. Measurement of each compartment makes up the steam cooker.

Thus,

(a) The total volume of the steam basket (cooking pot)

$$V = \pi r^2 h = 3.143 \times (23.5)^2 \times 24 = 41657.3\text{cm}^3. \tag{2}$$

Assuming we leave 1/3 of the total volume of the steam basket as a free space for swelling of the mash during steam cooking to form the attiéké

$$\begin{gathered} \frac{1}{3} \times 41657.3 = 13885.8\text{cm}^3, \\ 41657.3 - 13885.8 = 27\,771.5\text{cm}^3. \end{gathered} \tag{3}$$

The volume of the mash steam basket can accommodate is 27 771.5 cm^3.

(b) The total volume of water in the chamber (steam generation chamber)

$$V = \pi r^2 h V = 3.143 \times (25)^2 \times 3 V = 58931\text{cm}^3, \tag{4}$$

where r is the radius of the water can (diameter/2) and h is the height of the water.

The volume does not depend only on the volume of the attiéké mash but also (and more importantly) on the quantity of energy (heat) to be transferred from the steam to the attiéké to achieve complete cooking.

(c) The total volume of the charcoal/briquette combustion chamber

$$\begin{aligned} &V = \pi r^2 h, \\ &V = 3.143 \times (25)^2 \times 30\ V = 58931\ \text{cm}^3, \\ &r = \text{radius of the charcoal can} \left(\frac{\text{diameter}}{2}\right), \\ &h = \text{height of the charcoal can.} \end{aligned} \tag{5}$$

(d) The total volume of ash can

$$\begin{aligned} &V = \pi\, r^2 h = 3.143 \times (25)^2 \times 10, \\ &V = 19643.75\ \text{cm}^3. \end{aligned} \tag{6}$$

2.1.2. Heat Requirement. The amount of heat required to accomplish the cooking operation of attiéké was calculated by using Equations (7)–(12): The amount of water that is present in a material affects its thermal properties because these properties are functions of moisture content [18].

(a) Energy required for cooking 1 kg of mash to produce attiéké

$$Q_1 = M\text{Cp} \times (\delta T - \delta t), \tag{7}$$

where Q_1 is the amount of energy required (kJ). M is the mass of mash (kg). Cp is the specific heat capacity of mash (kJ/kg °C). δt is the initial temperature of mash before steam cooking (°C). δT is the final temperature of attiéké to be attained (°C).

We assumed that the amount of water in a material affects its thermal properties because these properties are functions of moisture content [18]. However, the specific heat capacity of the mash was based on the report by Alain et al. [19], who studied the physical properties of cassava mash and came about with the specific heat capacity of cassava mash before and after cooking.

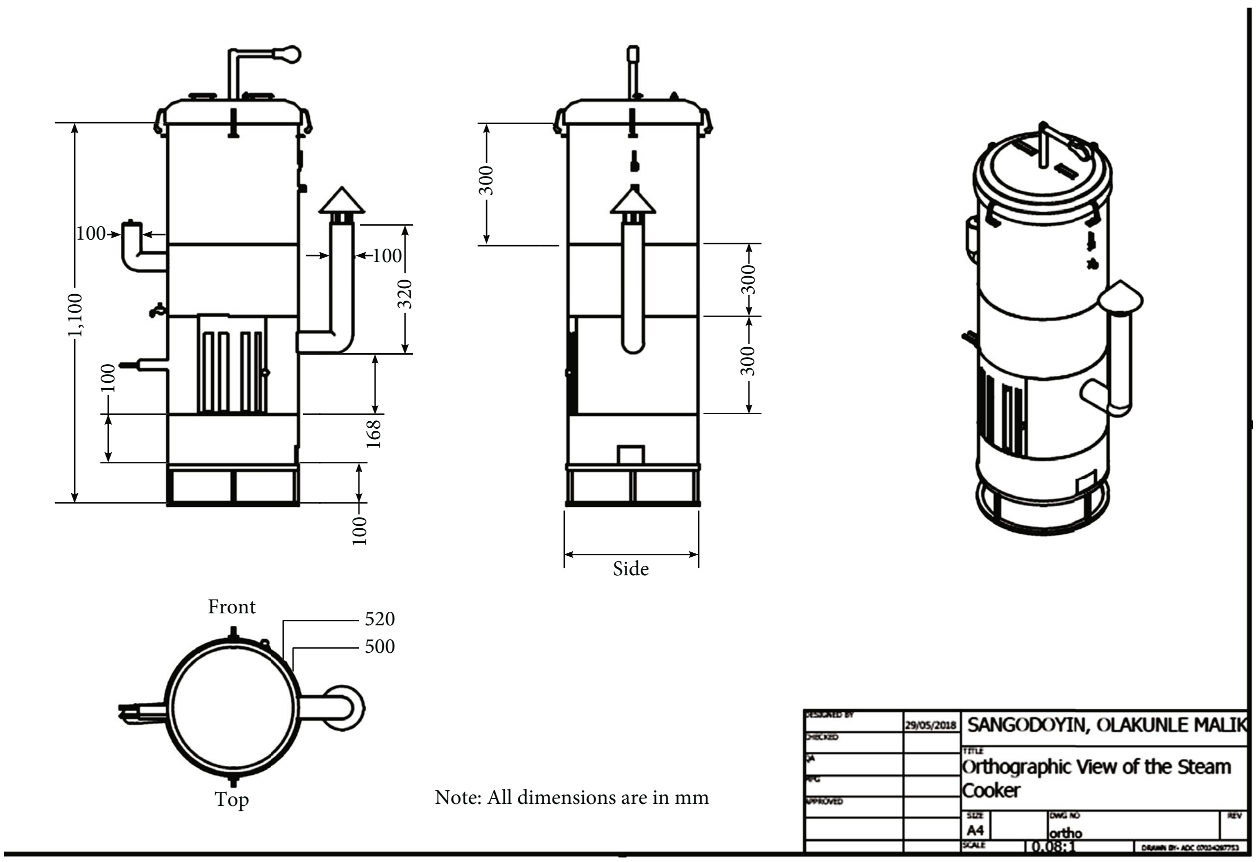


Figure 3: Orthogonal representation of the steam cooker.

(b) Energy required for evaporating water to generate steam (vaporization of water)

$$Q_2 = M \times h_{fg}, \tag{8}$$

where Q_2 is the amount of energy required (kJ). M is the mass of water (kg). h_{fg} is the latent heat of vaporization of water (kJ/kg °C).

(c) Energy required for heating the water to boiling point

$$Q_3 = M\mathrm{Cp} \times (\delta T - \delta t), \tag{9}$$

where Q_3 is the amount of energy required (kJ). M is the mass of mash (kg). Cp is the specific heat capacity of water (4.187 kJ/kg °C). δt is the initial temperature of water (°C). δT is the final temperature of water (°C).

(d) Energy required for heating up the water can

$$Q_4 = M\mathrm{Cp} \times (\delta T - \delta t), \tag{10}$$

where Q_4 is the amount of energy required (kJ). M is the mass of water (kg). Cp is the specific heat capacity of stainless steel (0.510 kJ/kg °C). δt is the initial temperature of water (°C). δT is the final temperature of water (°C).

The total energy required to accomplish the cooking operation of attiéké

$$Q = Q1 + Q_2 + Q_3 + Q_4. \tag{11}$$

Assuming the loss is 1/3 of the required energy for cooking.

Loss Q_L (kJ) = 1/3 × Q, and the cooking time has to be limited to 1 hour maximum.

Therefore, the total design energy required for cooking 1 kg of attiéké

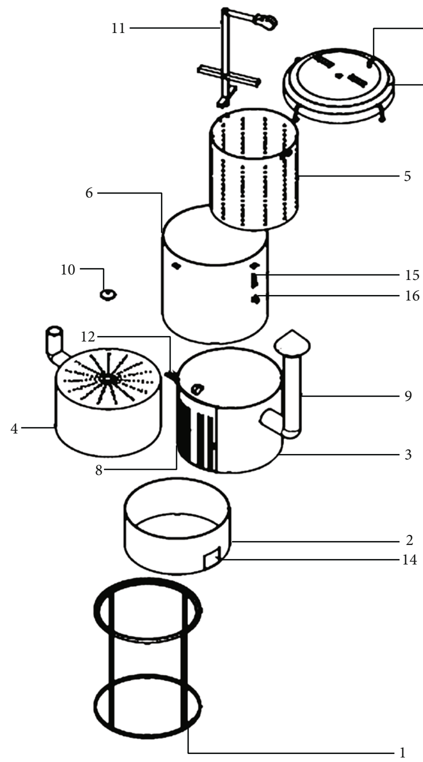
$$Q_D(\mathrm{MJ}) = Q + Q_L. \tag{12}$$

Steam consists of latent heat.

Hence, taking the average energy required to cook 1 kg of attieke = X, MJ.

Assuming the maximum temperature achieved to be 150°C and average temperature =145°C, then pressure =415.68 kpa and enthalpy of steam for 1 kg = 2739 kJ/kg:

$$\text{Amount of steam required (kg)} = \frac{\text{Average energy required to cook 1kg of attieke}}{\text{Enthalpy of steam for 1kg}}. \tag{13}$$



Parts list		
Item	Qty	Partnumber
1	1	Stand
2	1	Ash can
3	1	charcoal can
4	1	Water can
5	1	Cooking pot
6	1	Uppre container
7	1	Cover
8	1	Door
9	1	Smoke pipe cap
10	1	Water can cover
11	1	Atirrer
12	1	Bellows
13	1	Safety valve
14	1	Opening for ash
15	1	Thermometer
16	1	Thermostat

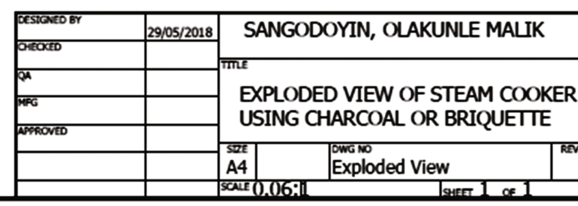


Figure 4: Exploded view of the constructed steamer.

2.1.3. Calculation of the Thickness of Each Compartment's Cylindrical Wall That Makes Up the Steam Cooker: The Upper Container and the Cooking Pot (Steam Basket). The cylindrical wall was subjected to the internal pressure of the steam and the weight of attiéké. The internal pressure acting on the long sides of the cylinder would give rise to circumferential stress in the wall of the cylinder. Thus, the circumferential stress was estimated using the equation below:

$$\text{Circumferential stress} = \sigma_1 = \frac{\text{Pr}}{t}. \quad (14)$$

where $\sigma 1$ is the tensile stress, Pr is the pressure, and t is the thickness.

The average tensile stress for stainless steel is 63.3 MPa [20]. The diameter of the cooking pot was calculated to be 0.25 m. The steam enters the cylinder at a pressure of 50 psi.

Therefore, the thickness of the cylindrical wall to tolerate the pressure of the steam was calculated as follows:

$$\begin{gathered}\sigma_1 = \frac{\text{Pr}}{t} 10^3, \\ 6.33 \times \frac{10^6 N}{\text{m}^2} = \frac{344.7 \times 10^3 N/\text{m}^2 \times 0.25}{t},\end{gathered} \quad (15)$$

Therefore, the minimum thickness required $a = 0.13613$ m.

Table 1 shows the data on the steamer dimensions (steamer cooker cover, steam basket, etc.) obtained from the abovementioned calculations.

2.2. Material Selection for Steamer Fabrication. The following materials were used for the fabrication of the steamer:

(a) *Stainless steel plate*: the stainless steel plate (review SS 316) is for constructing chambers directly from the food. It is one of the preferred sterile surfaces for preparing foods and is exceptionally simple to clean. Its gripping surface has no pores or splits to harbor soil or microscopic organisms. It is exceptionally alluring and requires minimal care since it does not rust easily. It will not affect the flavor because it does not respond to acidic foods during food preparation or cooking [21]

(b) *Mild steel plate*: a mild steel plate was used for the charcoal and ash cans, the chimney pipe, and the metal cap, while a 5 cm × 5 cm angle iron was used for the stand, consisting of four legs, each 40 cm long

(c) *Fasteners*: they were used to couple the components together

(d) *Mild steel and stainless electrodes*: they were used during the welding process. Bolts and nuts had a threading diameter of 10 mm. A bellow was

Table 1: Data showing the dimensions of the pilot steam cooker.

Specification	Value
The diameter of the steam-cooker cover (mm)	520
The total volume of the steam basket (cm^3)	41 657.3
The volume of mash that the steam basket can accommodate (cm^3)	27 771.5
The diameter of the steam basket (mm)	470
The height of the steam basket (mm)	270
The diameter of steam basket holes (mm)	0.005
The diameter of the cooking chamber (mm)	500
The height of the cooking chamber (mm)	300
The diameter of the water chamber (mm)	500
The height of the water chamber (mm)	300
The total volume of the water chamber (cm^3)	58 931
The diameter of the charcoal or briquette combustion chamber (mm)	500
The height of the charcoal or briquette combustion chamber (mm)	300
The total volume of ash can (cm^3)	19 643.75
The height of the hollow pipe (mm)	320
The diameter of the hollow pipe (mm)	100

constructed to aid the combustion of the charcoal/briquette through a blast of air

(e) *Nonpolar solvent*: the purpose of the solvent is to wash and clean the metal parts, which have been covered with oil and dust/debris and later washed with soap and pressurized steam

(f) *Iron wire brush*: this was used to brush off the dust from metal surfaces (especially the metal frame) and prepare the surfaces for painting

(g) *Paint*: Silver paint was used to coat, protect, and add lustre to the metal framework of the steam cooker

(h) *Brush*: a brush was used to apply paint to the steam cooker's surface

2.3. Evaluation of the Developed Steamer. The evaluation of the steamer for attiéké production was carried out at the Postharvest Engineering Unit of Facility Management Services (FMS) at IITA, Ibadan, Nigeria.

2.3.1. Source of Genetic Material. The cassava yellow-fleshed roots used in this study were three genotypes (IBA-011368 (sample 1), IBA-141092 (sample 2), and IBA-070593 (sample 3)) each of age 12 months. They were obtained from the Cassava Breeding Unit of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria.

2.3.2. Other Materials. All chemicals and reagents used are of analytical grade.

The following devices, apparatus, and equipment were used for carrying out all tests necessary in the steamer. (i) Thermocouples and digital thermometers were used to measure the temperature of the combustion chamber (hot gas). (ii) Weighing balance is used to measure all weights required. (iii) Thermometer is used to measure the temperature of the water. A digital dry bulb thermometer was used. (iv) Flexible metal rule was used to measure the metal plate for fabrication and dimension of the components of the steamer. (v) Stopwatch was used to measure the time required for boiling water, attiéké steaming, and charcoal combustion.

The three genotypes were processed to produce attiéké using the constructed steamer and a traditional steamer using the method described by Alfred et al. [22].

The improved steamer (Figure 2) was evaluated for water boiling and steaming, and the results recorded were used to compute the universally accepted indices of steamer performance as shown in Equations (16) and (17):

$$\text{Firepower, } P = \frac{QI - QF}{60I} \text{Cc(kilowatts)}. \quad QF = Mc \tag{16}$$

The equation above can be expressed as

$$P = \frac{QI - QF}{t} Cc, \tag{17}$$

where P is the firepower, I is the time elapsed in minutes, and Mc is the mass of wood burnt.

The specific fuel consumption (SC) for a steamer given by Krist-Spit and Sluimer [23] is the ratio of the total quantity of charcoal used in the cooking process to the amount of water used. For a steamer, the percentage of heat utilized may be defined as the percentage of heat released by the fire absorbed by the water in the water, as shown in Equation (18).

$$\text{PHU} = \frac{4.186 \times 10^3 \left[Mw_1\left(T_f - T_t\right) + 2260 \times 10^3 (Mw_1 - Mw_2)\right]}{\text{M}_\text{c}\text{C}_\text{c}}, \tag{18}$$

Table 2: Data on the traditional and pilot steamer's fuel consumption, water usage, and cooking time.

Parameter	Pilot steamer (charcoal) sample 1 (kg)	Traditional steamer (wood) sample 1 (kg)	Pilot steamer (charcoal) sample 2 (kg)	Traditional steamer (wood) sample 2 (kg)	Pilot steamer (charcoal) sample 3 (kg)	Traditional steamer (wood) sample 3 (kg)
The initial mass of fuel (kg)	11.306	15.006	10.306	13.000	10.000	12.000
The final mass of fuel (kg)	8.006	8.700	7.106	6.010	6.010	4.020
The initial mass of water (kg)	36.014	36.014	35.020	35.000	34.000	34.000
The final mass of water (kg)	35.054	34.012	34.120	34.010	33.010	32.080
The initial mass of attiéké mash (kg)	15.000	15.000	15.000	9.000	7.000	7.000
The final mass of attiéké (kg)	15.900	15.850	15.850	9.800	8.000	8.010
Steaming time (min)	15	30	12	25	10	27
Total time taken (min)	70	105	60	90	60	92
The initial water temperature before boiling (°C)	30	29	31	30	32	31
The final water temperature after boiling before steaming (°C)	100	100	102	101	102	101

Table 3: Summary of computed result for performance evaluation of both the traditional and developed pilot steamer.

Parameters	Pilot steamer (charcoal) sample 1 (kg)	Traditional steamer (wood) sample 1 (kg)	Pilot steamer (charcoal) sample 2 (kg)	Traditional steamer (wood) sample 2 (kg)	Pilot steamer (charcoal) sample 3 (kg)	Traditional steamer (wood) sample 3 (kg)
The initial mass of water (kg)	36.014	36.014	35.020	35.000	34.000	34.000
The final mass of water (kg)	35.054	34.012	34.120	34.010	33.01	32.080
Mass of water evaporated (kg)	0.96	2.00	0.90	0.99	0.99	1.92
Time taken to boil (minutes)	55	75	48	65	50	65
Mass of fuel burnt (kg)	3.300	6.300	3.200	6.990	3.990	7.980
Fire power (MW)	31.000	43.441	34.444	55.662	41.230	63.43
Percentage heat utilized (PHU) %	12.436	7.789	12.542	5.833	9.863	5.781
Specific consumption (%)	0.0916	0.175	0.0914	0.1997	0.1174	0.235

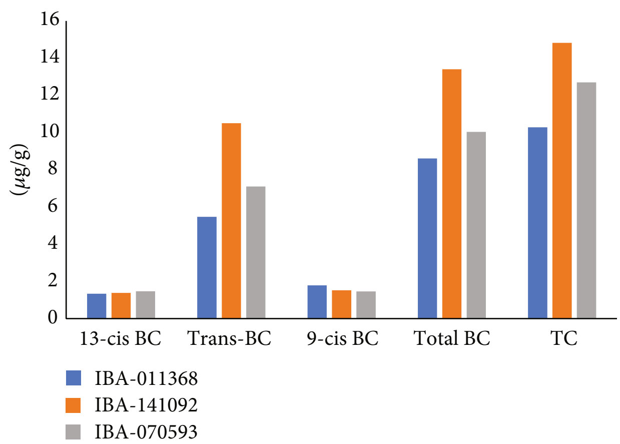


FIGURE 5: Total carotenoid and β-carotene contents of the raw roots of the three yellow-fleshed cassava genotypes. BC = β-carotene; TC = total carotenoid.

where PHU is the percent heat utilized; Mw_1 is the initial mass of water; T_t is the initial temperature of water; T_f is the final temperature of water; Mw_2 is the final mass of water; MC is the mass of fuel burnt.

Specific heat of water = 4.186 kJ/kg and latent heat of vaporization of water at atmospheric pressure = 2260 kJ/kg. The moisture content of the wood was 7.0%, while that of charcoal, the by-product of the combustion of wood, was 4.1%. The calorific value of fuelwood was determined as 18 400 kJ/kg, and that of charcoal was 27 600 kJ/kg.

2.4. Carotenoid Analysis Using High-Performance Liquid Chromatography (HPLC). The carotenoid analysis was carried out using the method described by Maziya-Dixon et al. [24]. The HPLC system (Water Corporation, Milford, MA) comprised a C30 YMC carotenoid guard column (4.6 × 250 mm, 3 μL), binary pump (Waters 626), autosampler (Waters 717), and photodiode array detector (Waters 2996). The mobile phase consisted of methanol (980 mL) with chloroform (20 mL), a flow rate of 2.0 mL/min, and an injection volume of 75 mL. The samples were examined at a wavelength of 450 nm. The total carotenoid content (TCC) was calculated using Equation (19).

$$\text{Total carotenoid content}\left(\frac{\text{ug}}{\text{g}}\right) = \frac{A \times V(\text{mL}) \times 10000}{A_1 \times P(g)}, \tag{19}$$

where A is the absorbance, V is the total extract volume, P is the sample weight, and A_1 is the carotene extinction coefficient in petroleum ether.

The carotene content was calculated using Equation (20).

$$\text{Carotene content}\left(\frac{\text{ug}}{\text{g}}\right) = \frac{\text{Ax} \times \text{Cs}(\text{ug/mL}) \times V(mL)}{As \times P(g)}, \tag{20}$$

where Ax is the carotenoid peak area, Cs is the standard concentration, A_s is the standard area, V is the total extract volume, and P is the sample weight.

The methods and formula of Murphy et al. [25] and Rodriguez-Amaya [17] were used for the true retention (TR) estimation.

2.5. Calculation of True and Apparent Retention of Total Carotenoids in Cooked Attiéké. The true and apparent retentions of total carotenoids for attiéké produced by the improved and traditional cookers were calculated using Equations (21) and (22), respectively.

(i) True retention

$$\%\text{TR}\,\frac{\text{trans} - \beta - \text{carotene content per kg of processed sample} \times \text{weight of processed sample.kg}}{\text{trans} - \beta - \text{carotene content per kg of peeled roots} \times \text{weight of peeled roots.kg}} \times 100. \tag{21}$$

(ii) Apparent retention

$$\%\text{AR} = \frac{\text{trans} - \beta - \text{carotene content per kg of cooked attieke(dry basis)}}{\text{trans} - \beta - \text{content per kg of peeled roots(dry basis)}} \times 100. \tag{22}$$

2.6. Product Yield. Equation (23) was used to calculate the product yield (PY), which is the percentage mass of the product that remains after each stage and is based on the initial mass of unpeeled roots (100 percent).

$$\text{PY\%} = \frac{\text{weight of sample during processing.kg}}{\text{initial sample weight.kg}} \times 100. \tag{23}$$

2.7. Statistical Analysis. Analysis of variance was performed on all generated data (ANOVA). Duncan's multiple range test was used to separate means at a 5% probability level using a computer software package IBM SPSS Statistics for Windows, Version 20.0.

3. Results and Discussions

3.1. Steaming Efficiency of Traditional and Developed Steamers. Table 2 shows the data on fuel consumption, water

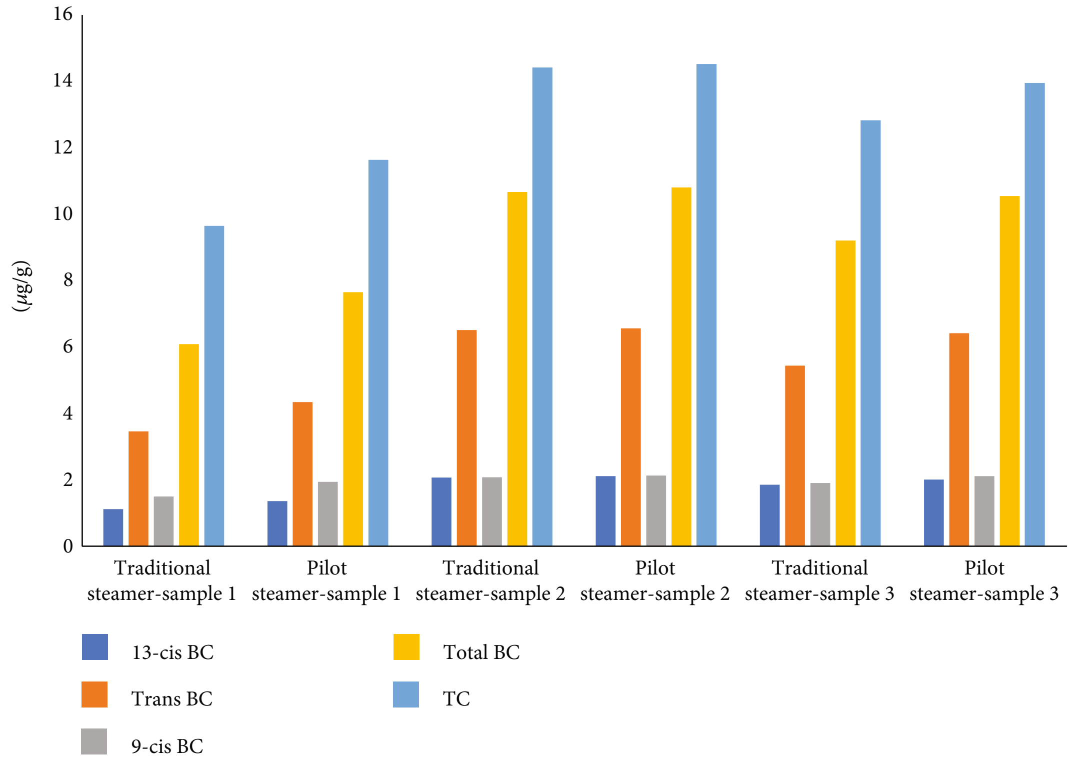


Figure 6: Total carotenoid and β-carotene contents of attiéké samples produced by the traditional and pilot steamers. BC = β-carotene; TC = total carotenoid, IBA-011368 (sample 1), IBA-141092 (sample 2), and IB-070593 (sample 3).

usage, and cooking time for the traditional and pilot steamers. The maximum temperature inside the chamber before steam production was 102°C, with boiling water at 100°C. The steaming time difference between the developed steamer and the traditional steamer was 15, 13, and 17 minutes for samples 1, 2, and 3, respectively. However, the differences in the total cooking time taken by the developed and traditional steamers for samples 1, 2, and 3 were 35, 30, and 32 minutes, respectively, using each of its most appropriate energy source, which is wood for the traditional cooker and charcoal for the improved cooker. Thus, the developed steamer was able to cook attiéké more quickly (an average of 1.5 times faster). The fuel consumption rates of the three genotypes of roots used varied. Although the aim was not to compare wood to charcoal, it is worth noting that the study showed that the developed steamer consumed 3.3 kg of charcoal to cook attiéké for 1 h 10 min in sample 1 (Genotype 1BA-011368), while the traditional steamer consumed 6.3 kg of wood to cook attiéké for 1 hour and 45 minutes. When comparing the steamers' fuel consumption and cooking time duration, there were differences of 3.0 kg and 35 minutes, respectively, for sample 1.

Moreover, these differences were 3.8 kg and 30 minutes for sample 2 (IBA-141092) and 4.0 kg and 32 minutes for sample 3 (IBA-070593). It could be concluded that the developed steamer consumed less of its fuel (charcoal) and cooked faster than the traditional steamer that was also using its best-suited fuel (wood) for attiéké preparation from yellow-fleshed cassava. The time-saving findings and, to some extent, the energy savings could translate to an excellent processing cost reduction for the attiéké processors with better working conditions.

Table 3 shows the performance evaluation of the improved and the traditional cookers. The improved steam cooker's fuel firepower (fp) ranged from 31 to 41 MW, while the traditional steam cooker's ranged from 43 to 63 MW. The improved steam cooker had a specific fuel consumption (SC) of 0.12 kg/kWh, while the traditional steam cooker had a specific fuel consumption (SC) of 0.24 kg/kW. The pilot steam cooker's heat (PHU) ranged from 12 to 13 percent (or 12 percent-13 percent thermal efficiency), whereas the traditional steam cooker's from 6 to 8 percent. The tests yielded a 13 percent efficiency. The improved steam cooker outperformed the traditional steam cooker by about 8%; this steamer could steam-cook attiéké in a shorter time (about 1.5 times faster), with the highest percentage of heat utilization standing at 2.6 times less fuel. We consider this steamer a prototype, and we hope to improve the improved cooker further by taking care of the materials and some dispositions (like lagging the heating chamber that was not incorporated if included, which would have decreased the heat loss on the improved cooker).

3.2. Carotenoid Content and Retention in Cooked Attiéké. The total carotenoid and β-carotene contents of fresh raw roots of the three biofortified cassava genotypes are shown

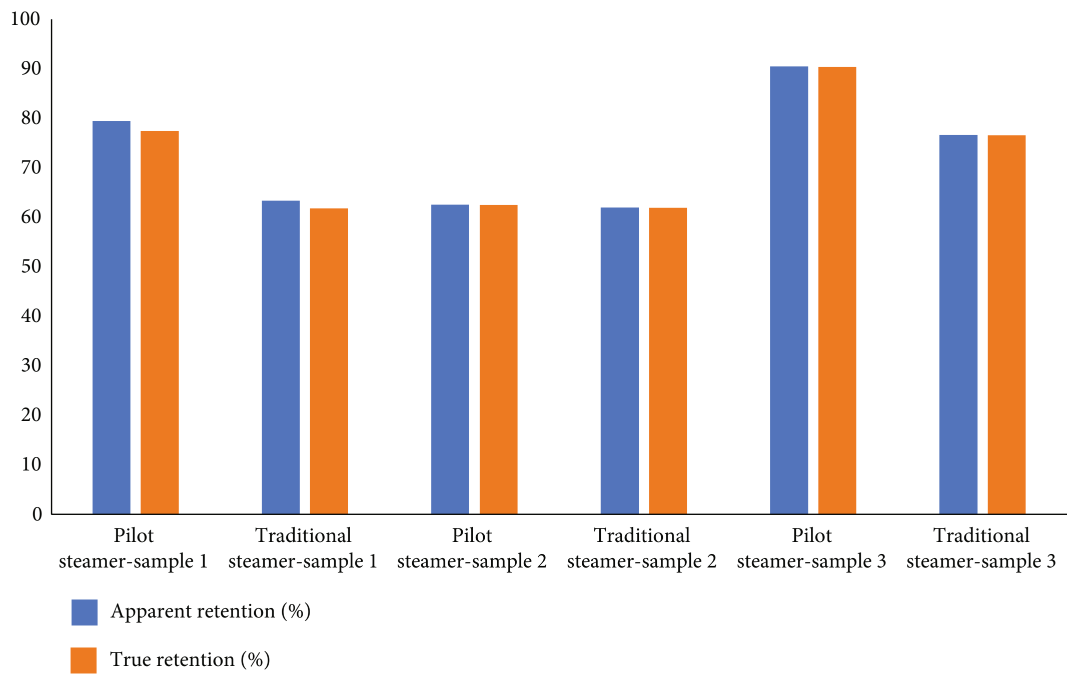


Figure 7: True and apparent retention of total carotenoids in attiéké produced from three selected cassava genotypes by the traditional and pilot steamers. IBA-011368 (sample 1), IBA-141092 (sample 2), and IB-070593 (sample 3).

Table 4: Estimated cost of the developed steamer.

Specification	Qty	Amount spent ($)
2 mm, stainless steel (plate)	1.0	214.0
2 mm mild steel (plate)	1.0	46.0
Bolts, nuts, and washers (set)	24.0	14.0
Bellow (set)	1.0	10.0
Mild steel electrode (packet)	0.5	6.0
Stainless steel electrode (packet)	0.5	29.0
Cutting disk (unit)	1.0	1.1
Grinding disk (unit)	1.0	2.7
Sieving cloth, flat bar, iron rod, wire mesh, and fiberglass (various, according to the type of material as required)	A/R[†]	120.0
Instruments and additional materials (press gauge, manifold, rod, and iron tape)	A/R	37.5
Subtotal material		480.3
Labor (as 30% of the cost of materials)		144.09
Grand total		624.39

[†]A/R = as required.

in Figure 5. The highest total carotenoid and *trans-β*-carotene levels are found in genotype IBA-141092 (sample 2), followed by genotype IBA-070593 (sample 3). However, the levels of the cis-isomers (9-cis and 13-cis) appear the same in all three genotypes studied. The values of carotenoids obtained for these genotypes agree with what Maziya-Dixon et al. [16] obtained in the yellow-fleshed cassava genotypes grown in the same location.

However, Figure 6 also compares the total carotenoid and *β*-carotene contents of attiéké samples steam-cooked by the two steamers. The total carotenoids and total *β*-carotene contents of the cooked attiéké samples from the developed (pilot) steamer were consistently higher than that of the traditional steamer. However, considering the isomers of *β*-carotene, it was observed that the *trans-β*-carotene contents of attiéké samples from the developed steamer are higher than that of the traditional steamer across the genotypes. Nevertheless, the 9-cis and 13-cis-isomers look similar. We can conclude that the steaming process significantly impacted the *trans*-isomers more than the *cis*-isomers.

Figure 7 shows the true and apparent retention of carotenoids in attiéké produced from three selected cassava genotypes by the traditional and pilot steamers. Generally, the pilot steamer's apparent and true retention values are higher for all three genotypes than the traditional steamer's. Sample 3 (genotype IBA-070593) of the developed steamer had the highest carotenoid retention value, followed by sample 1 (IBA-011368). Moreover, sample 3 showed the highest carotenoid retention using the traditional steamer. The genotype IBA-070593 is a good cassava variety for producing attiéké from yellow-fleshed cassava. However, a sensory test on this sample is required to determine the most acceptable attiéké samples. Higher retention may not always be associated with acceptable sensory quality. More testing with different traditional steamers and evaluating the developed steamers with attiéké processors are recommended to determine the likelihood of acceptance of this good steamer.

3.3. Steamer Production Cost Analysis. Table 4 shows the estimated cost of materials for the developed steamer. It is an excellent idea to give the estimated cost of the developed steamer as it has been found in this study that it is more effective than the traditional method. The cost of the machine includes the cost of the materials brought to the engineering workshop and the accompanying accessories and labor. The total cost of the equipment is approximately US$630 (Table 2). The affordability of the developed steamer may be part of our future work to lower the cost below the current one, but we believe it will be affordable for small- and medium-scale attiéké processors for mass production.

4. Conclusion

A renewable energy steam cooker was built at the IITA in Ibadan, Nigeria. Its performance and carotene retention were compared to a traditional steamer using three different biofortified yellow cassava root genotypes. The study found that the constructed steamer took less time (1.5 times faster) to bring water to the boiling point and consumed less fuel (2.6 times less) than the traditional steamer while using 1.7 times less water and taking 2.6 times less time to cook the same batch. The traditional steamer retained 12.95% true β-carotene. The study also revealed that the newly built steamer outperforms traditional steamers regarding β-carotene retention and efficiency. The developed steamer is cost-effective as the price per unit is $630. We recommend that this newly constructed pilot steam cooker be evaluated and optimized, preferably in the country of attiéké itself, with professional processors, and that it be compared with the best steamers locally available. Based on the findings, some changes can be made, and the optimized steamer can be replicated at least ten times for scaling across countries. The developed steamer will be affordable and may be recommended for small- and medium-scale attiéké processors when mass-produced.

Data Availability

The data supporting the results reported in this paper are available on request from the corresponding author (e-mail: o.alamu@cgiar.org.

Disclosure

This study was presented as a poster presentation at the International Association of Research Scholars and Fellows's (IARSAF) 22nd Annual Symposium at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this article.

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References

[1] B. Assanvo, G. N. Agbo, Y. Behi, P. Coulin, and Z. Farah, "Microflora of traditional starter made from cassava for "attieke" production in Dabou (Cote d'Ivoire)," *Journal of Food Control*, vol. 17, no. 1, pp. 37–41, 2006.

[2] F. Aboua, "Optimization of traditional fermentation of cassava," *Journal of Tropical Science*, vol. 35, pp. 68–75, 1995.

[3] N. Djéni, K. F. N'guessan, D. M. Toka, K. A. Kouame, and K. M. Dje, "Quality of *attieke* (a fermented cassava product) from the three main processing zones in C ote d'Ivoire," *Food Research International*, vol. 44, no. 1, pp. 410–416, 2011.

[4] T. N. Djéni, A. K. Kouamé, J.-P. K. M. Bouatenin, F. K. N'Guessan, and M. K. Djè, "Process of attieke production in Côte d'Ivoire: new trends, updates and effects on quality and preference of the food," *International Journal of Advanced Research*, vol. 2, no. 8, pp. 644–653, 2014.

[5] F. Aboua, A. Kossa, K. Konan, K. Mosso, S. Agbo, and A. Kamenan, "Analyse de quelques constituants du manioc au cours de la préparation de l'attiéké," in *La Post-Récolte en Afrique: Séminaire International Abidjan*, K. Foua Bi and B. J. R. Philomène, Eds., pp. 217–221, Montmagny QC Marquis Publishers, Côte d'Ivoire, 1990.

[6] A. Diop, "L'attiéké dans la région d'Abidjan, analyse économique de la filière traditionnelle à travers quelques types d'organisation (Adjoukrou, Ebrié, Attié). Thèse de Doctorat troisième cycle en Economie rurale," Université de Cocody,

Abidjan, Côte d'Ivoire, 1992, http://archives.uvci.edu.ci:52003/data/THESES_SCIENCES_ECO/_636928215578070381.pdf. Acessed online 10/06/2020.

[7] A. K. Kouamé, M. D. Toka, K. M. Jean-Paul et al., "Microbiology hazard in inputs (traditional cassava inocula, water and oil palm) used in attieke process in south of Côte d'Ivoire," *Microbiology Research Journal International*, vol. 20, no. 3, pp. 1–14, 2017.

[8] A. L. Chavez, T. Sánchez, H. Ceballos et al., "Retention of carotenoids in cassava roots submitted to different processing methods," *Journal of Food Agriculture*, vol. 87, pp. 388–393, 2002.

[9] A. M. Jaramillo, L. F. Londoño, J. C. Orozco et al., "A comparison study of five different methods to measure carotenoids in biofortified yellow cassava (*Manihot esculenta*)," *PLoS One*, vol. 13, no. 12, article e0209702, 2018.

[10] S. Huang, J. Yang, and Y. Lee, "Interactions of heat and mass transfer in steam reheating of starchy foods," *Journal of Food Engineering*, vol. 114, no. 2, pp. 174–182, 2013.

[11] C. Fang and M. S. Chinnan, "Kinetics of cowpea starch gelatinization and modeling of starch gelatinization during steaming of intact cowpea seed," *LWT-Food Science and Technology*, vol. 37, no. 3, pp. 345–354, 2004.

[12] A. G. F. Stapley, K. A. Landman, C. P. Please, and P. J. Fryer, "Understanding wheat grain steaming, Industrial & Engineering Chemistry Research teaming data," *Engineering and Science*, vol. 54, p. 965, 2003.

[13] P. M. T. Akely, Y. Djina, B. R. Konan, K. Irie, L. P. Kouame, and N. G. Amani, "Study of varietal influence post conservation on biochemical and sensory qualities of attieke and boiled cassava (Manihot esculenta Crantz)," *Agricultural Sciences*, vol. 7, no. 3, pp. 127–136, 2016.

[14] E. R. Krabi, A. A. Assamoi, A. F. Ehon, D. Bréhima, L. S. Niamké, and P. Thonart, "Production d'attiéké (couscous à base de manioc fermenté) dans la ville d'Abidjan," *European Scientific Journal*, vol. 11, pp. 1857–7881, 2015.

[15] G. Pierre, M. Graber, F. Orvain, C. Dupuy, and T. Maugard, "Biochemical characterization of extracellular polymeric substances extracted from an intertidal mudflat using a cation exchange resin," *Biochemical Systematics and Ecology*, vol. 38, no. 5, pp. 917–923, 2010.

[16] B. Maziya-Dixon, A. G. O. Dixon, and G. Ssemakula, "Changes in total carotenoid content at different stages of traditional processing of yellow-fleshed cassava genotypes," *International Journal of Food Science & Technology*, vol. 44, no. 12, pp. 2350–2357, 2009.

[17] D. B. Rodriguez-Amaya, *Carotenoids and Food Preparation: The Retention of Provitamin A Carotenoids in Prepared, Processed, and Stored Foods*, OMNI/USAID, Washington, D.C., 1997.

[18] A. S. Oyerinde and A. P. Olalusi, "Thermal properties of ground & fermented cassava mash (Gari) during different stages of roasting," *Journal of Industrial Research and Technology*, vol. 3, no. 1, 2011.

[19] G. Alain, G. Chuzel, S. Didier, and J. Andrieu, "Physical properties of cassava mash," *International Journal of Food Science*, vol. 24, no. 6, p. 645, 1989.

[20] M. Z. Naser and V. Uppala, "Properties and material models for construction materials post exposure to elevated temperatures," *Mechanics of Materials*, vol. 142, article 103293, 2020.

[21] A. Fussel, "Why Use Stainless Steel In The Food Processing Industry?," 2017, https://www.diversifiedmetals.com/use-stainless-steel-food-processing-industry/.

[22] K. Alfred, K. M. Jean-Paul, B. Bouatenin, A. Zamblé, C. Boli, and N. Theodore, "Djéniand technical sheet of process of attieke production in Côte d'Ivoire," *Research & Reviews Journal of Food and Dairy Technology*, vol. 5, no. 4, 2017.

[23] C. E. Krist-Spit and P. Sluimer, "Heat transfer in ovens during the baking of bread," in *Cereals in a European Context, First European Conference on Food Science and Technology*, I. D. Morton, Ed., pp. 344–354, Ellis Horwood Publishers, Chichester, UK, 1987.

[24] B. Maziya-Dixon, E. O. Alamu, and G. A. Dixon, "Variation in the evaluation of cis- and trans-carotene in yellow-fleshed cassava (*Manihot esculenta* Cranz) varieties as a function of the storage root portion and sampling method," *Food Science and Technology*, vol. 70, pp. 296–301, 2016.

[25] E. W. Murphy, P. E. Criner, and B. C. Gra, "Comparisons of methods for calculating retention of nutrients in cooked foods," *Journal of Agriculture. Food Chemistry*, vol. 23, no. 6, pp. 1153–1157, 1995.