Chapter

Recent Developments in Processing Technologies for Roasted, Fried, Smoked and Fermented Food Products

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Abstract

Progress in the research efforts to upgrade various traditional processing technologies, especially roasting, deep-fat frying, smoking, and fermentation, is presented in this chapter. The importance of these studies is in the need for more user-friendly, adaptable, and affordable low-cost machinery and equipment for sustainable food processing, especially in communities where electricity is a challenge, and alternative energy sources such as gas and charcoal are critical. The design considerations and characteristics of the various types of machinery as well as the design calculations and performance evaluation results aimed at standardizing the upgraded machinery are therefore presented from various studies. The effects of these technologies on the quality of the resulting products are discussed particularly in relation to the variations in process losses of micronutrients in the fortified products, with examples of vitamin A and iron losses in pan bread and fried doughnuts obtained from baking fortified wheat flours.

Keywords: roasting, frying, smoking, fermentation, product quality, fortification

1. Introduction

Recent progress in the research efforts to upgrade four traditional processing technologies of roasting, frying, smoking, and fermented products is examined in this chapter. Most food processing activities in rural and urban areas in developing countries, whether at the household level or especially at the micro- and small-scale business levels, have for centuries depended on the use of these technologies at the rural scale for human existence [1, 2]. These upgrade efforts are therefore aimed at making life less burdensome by developing more user-friendly and affordable low-cost machinery, in recognition of changing socioeconomic circumstances [3]. This interest has continued to engage the focus of agricultural engineers and food scientists in the last two decades, especially with the prevalence of electricity challenges in most rural communities all over the world and the need for alternative sources of energy.

However, many research studies reported in the literature had until recently been aimed at standardizing the processing technologies for traditional crops like cassava and plantain into dry flour forms to extend their shelf-life [2, 4, 5]. However, in recent years, work has shifted to standardizing the engineering parameters applicable to each of these processing technologies through a better understanding of the fundamentals of the design characteristics, design calculations, and performance evaluation, to enable the construction of such upgraded devices for markets. Testing and validation results of the functionality of these upgrades have also shown the tremendous advances that have been made in the achievement of these objectives [6–8].

The effects of these technologies on the quality of fortified products, in the face of the increasing role of fortification in addressing micronutrient deficiencies in many developing countries, are also examined in this chapter. The likely process losses associated with roasted, fried, baked, and fermented products are discussed, and examples of the associated process losses of baked fortified products, namely pan bread and fried doughnuts, are presented. Losses in vitamin A and iron in these products are shown to be as high as 30–40%, which shows the importance of the type of vitamin-mineral premixes suitable for use in different products and the relationship with the type of processing technology to be adopted.

1.1 Roasting

In roasting, various agricultural products such as yams, plantains, maize, and potatoes are exposed to dry heat over a fire, or in an oven, and cooked to a state in which sufficient moisture has been removed to make the products suitable for immediate consumption. For example, the traditional method of roasting plantain is to place a metal grill on top of a metal pot containing burning charcoal, which supplies the heat to roast the plantain. The use of uncontrolled heat sources [9] has been the most common application of this technology, with an emphasis on convective heat transfer, rather than on a more efficient process by a combination of conduction, convection, and radiation. However, it is noteworthy that recent research reports have examined the application of emerging and more novel techniques such as infra-red heating to the roasting of nuts. The limitations of these technologies have also been highlighted [10, 11].

The increasing demand for roasted products such as semi-ripe plantains has brought about recent interest to upgrade the local method of roasting to be more user-friendly, hygienic, and versatile. In fact, studies on the development of a low-cost and affordable multi-heat source plantain roaster have been undertaken and the performance characteristics of such roaster examined from the effects of using different heat sources, namely, charcoal, gas, and electricity, on the proximate and micronutrient composition of the roasted product. The roasting process has been reported to prevent toxic hydrocarbons as well as microbial contamination. One other advantage reported is the suitability of such products for diabetics [12, 13].

Many studies have also been reported on the development of roasting machines [6, 7, 9]. During the roasting process, there is a transmission of energy from the heat source to the plantain as a result of a temperature gradient. This alters the quality of the food with an enhanced flavor due to some desirable physical and chemical changes. This desirable quality has been attributed to the reduction of the water activity at the surface of the food [14]. Whether the source of heat is gas, electricity, or charcoal, the use of high temperature in roasting facilitates complex changes in the components of the food at the surface and retention of moisture in the interior of the food product. A specific example of such an upgraded and versatile technology is given here, which has high commercial potential in many rural communities as it can employ either charcoal, gas, or electricity, as heat sources for the roasting of plantains, traditionally known as "*Booli*" [15].

1.1.1 Methodology

1.1.1.1 Design characteristics of the multi-heat source plantain roaster

The plantain roaster was designed to use any of the three alternative energy sources, namely, electricity, gas, and standard charcoal. The major components (**Figure 1**) have been described in detail [14] and comprise a cylindrical stainless steel basket, a thermostat, heater, and fan, among others. Separate sections are provided for a gas burner, electric heater, and charcoal departments, while the roasting net is held by a stainless steel standing support and designed in such a way as to enable free movement of the turning handle, which fits into a fabricated frame. Free movement of the heat by conduction, convection, and radiation was found possible with this arrangement [14]. The electric heater is welded to the frame, fitted with an electric heater with a power of 1800 W and a sensor to detect changes in temperature and trip off automatically at the set temperature. The design also holds a load of 2 kg charcoal for heating the plantain in the compartment provided, while the gas cylinder is connected to the burner with a long hose (**Figure 1**).

1.1.1.2 Performance Trials

The plantain roaster was observed to be heated to 200°C while empty with both electric and gas sources and to 190°C when using charcoal as the heat source. Temperature regulation is achieved for the electric heater with an electric switch that regularly trips off and switches back on as necessary. The cycle of pressure decrease

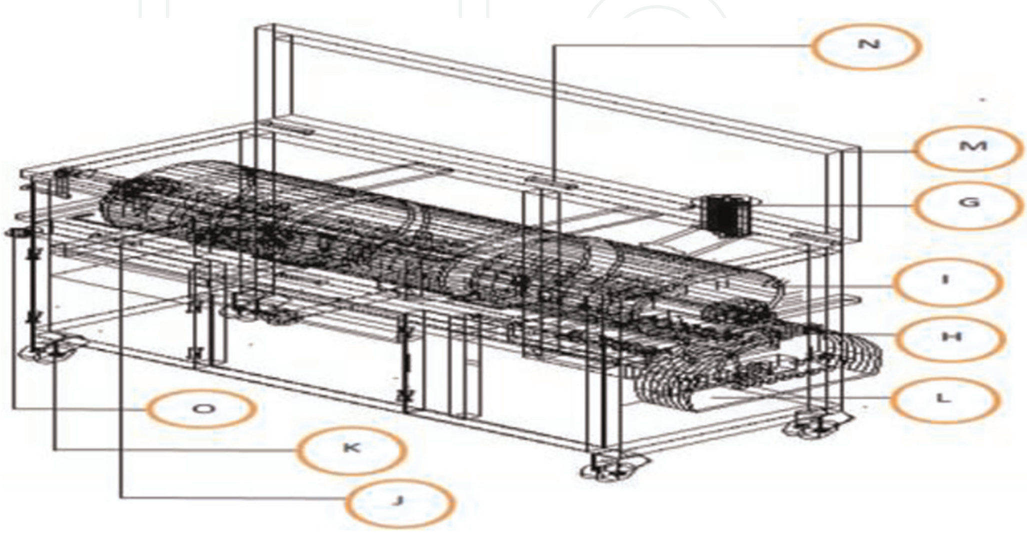

Figure 1.
The design of the plantain roaster: G—chimney, H—the turning handle, I—roasting basket, J—door handle, K—the tyre, L—fan compartment, M—lid cover, N—hinges, O—control switch.

and increase is used to control the rate at which the gas flows, with gas regulated on the basis of the color of the flame produced, while the charcoal is tested by the level of heat it produces when empty. The efficiency of the charcoal when it produces energy is tested compared to the volume of charcoal in the compartment [14].

The optimum temperature for both electric and gas sources was observed to be 200°C while that of charcoal was 190°C, these being the temperatures at which the plantain attained an acceptable color in the shortest time. The ambient temperature was 30°C.

1.1.1.3 Performance calculations

$$\text{Using the eq.}Q = -KA\frac{dt}{dx} \tag{1}$$

where Q is heat transferred by conduction, K is the thermal conductivity of the stainless steel roasting net, and the minus sign indicates that it obeys the second law of thermodynamics, A is the cross-sectional area of the roasting net through which heat flows to the plantain, and $\partial T/\partial x$ is the temperature gradient in the direction of heat flow.

$$\mathrm{Q} = \mathrm{Q_{conv}} + \mathrm{Q_{cond}} + \mathrm{Q_{rad}} \tag{2}$$

$$\mathrm{Q} = \left[hA\left(t_s - t_f\right) + \left(-K_pA\frac{dt}{dx}\right)\right] + \mathrm{Q_{rad}} \tag{3}$$

where Q_{conv}, Q_{cond}, and Q_{rad} represent heat transfer by convection, conduction, and radiation, respectively; h is the convective heat transfer coefficient of 31.77 $W/m^2{}^\circ C$ [16]; K_p is the thermal conductivity of the plantain 0.594 W/m°C; t_f is average room temperature before heating in °C; and t_s is surface temperature of the plantain in °C.

The mass (m_1) of different unripe plantains was weighed to an average of 130 g. A maximum load of seven fingers of unripe plantain per cycle averaged 0.91 kg. The selection of unripe plantain for this study is in line with the WHO recommendation for diabetes patients, arising from current global health challenges and the exponential growth of chronic diseases [17].

$$\text{Machine Capacity (kg/h)} = \frac{W}{T} \tag{4}$$

where W is the weight of plantain fingers (kg), and T is the time taken to roast the plantain (h).

$$\text{Efficiency of the machine (\%)} = \frac{E_1}{E_2} \times 100 \tag{5}$$

where E_1 is the energy output, and E_2 is the energy input.

The force required to turn the weight of the plantain during roasting.

$$\mathrm{F} = \mathrm{m_1 g} \tag{6}$$

$$\mathrm{P^1} = \mathrm{m_2 gL} \tag{7}$$

where P^1 is the power requirement to turn the empty basket, m_2 is the mass of the rod, g is the center of gravity, and L is the length of the roasting basket.

$$= 100.33\ \text{W}.$$

$$P = m_2gL + F \tag{8}$$

where P is the power requirement to turn the basket with plantain.

$$= 100.33 + (0.91 \times 9.8 \times 0.273)$$
$$= 102.77\ \text{W}.$$

Thus, the power requirement to turn the handle is 102.77 W. This falls within the sustainable human potential power of 70–500 W.

1.1.2 Sensory evaluation of results

Consumer assessment of the overall acceptability of the roasted plantain was carried out following the method described [15]. Twenty male and twenty female staff of Bells University of Technology, Ota, Nigeria, were selected randomly from regular consumers of roasted plantain for the evaluation. Coded samples were placed in separate identical tight polythene bags and assessed using a questionnaire among the forty respondents for color, flavor, hardness, moisture release, and chewiness on a hedonic scale of 1–5 points where: 1 = poor and 5 = excellent.

1.1.3 Performance evaluation results

From the experimental trials, the plantain roaster was observed to take 20 minutes for electric and gas sources and 25 minutes for the charcoal heat source to reach the desired temperatures of 200°C and 190°C, respectively, for the seven fingers of plantain per roasting cycle per compartment. The chamber temperatures were observed to drop by 20, 15, and 15°C, respectively, for the electric, gas, and charcoal sources after loading

Figure 2.
Snapshot of plantain roaster.

Figure 3.
Roasted plantain using a gas heat source (a), electric heat source (b), and charcoal heat source (c).

[14]. The plantain roaster is shown (**Figure 2**) below, with the color gradually changing to brown as shown in the figures a, b and, c for gas, electric, and charcoal heat sources, respectively. The interplay of heat by conduction on the roasted product (*booli*) as well as by convection and radiation has been well explained [14].

While the average capacity of the machine was 3.74 kg/h and the machine efficiency was 96.32% in each of the three compartments, radiation heat loss was 31.07, 31.07, and 29.23 W for the gas, electric, and charcoal heat sources, respectively; **Figure 3** below also shows the roasted products obtained.

The results of the performance evaluation of the roaster on the different heat sources are presented in **Tables 1–4** below.

From the heat transfer rates (**Table 1**) above, it is evident that over 60% of the heat supplied is derived from conduction. From the results of the proximate analysis (**Table 2**), moisture loss is the highest in the charcoal-roasted product, while sensory

Roaster compartment	Heat supplied (W)	Heat of conduction (W)	Heat of convection (W)	Heat of radiation (W)
Gas	846.28	538.02	277.19	31.07
Electric	846.28	538.02	277.19	31.07
Charcoal	793.60	506.37	258.00	29.23

Table 1.
Heat transfer rate for the roasting machine.

Test sample	Moisture (%)	Ash (%)	Crude fiber (%)	Carbohydrate (%)	Fat (%)	Protein (%)
Fresh	$58.27^{a} \pm 0.58$	$5.89^{c} \pm 0.13$	$2.83^{a} \pm 0.07$	$23.80^{a} \pm 0.24$	$2.16^{a} \pm 31$	$6.90^{a} \pm 16$
Gas	$46.26^{b} \pm 0.40$	$7.45^{b} \pm 0.53$	$3.27^{b} \pm 28$	$33.41^{d} \pm 0.38$	$4.52^{c} \pm 0.03$	$8.11^{b} \pm 0.15$
Electric	$45.94^{b} \pm 0.21$	$8.30^{a} \pm 0.12$	$3.41^{b} \pm 0.22$	$32.35^{b} \pm 0.45$	$4.68^{b} \pm 0.32$	$8.35^{b} \pm 0.14$
Charcoal	$39.59^{c} \pm 0.53$	$7.00^{b} \pm 0.05$	$3.43^{b} \pm 0.17$	$43.02^{c} \pm 0.14$	$4.64^{c} \pm 0.44$	$5.38^{c} \pm 0.30$

Data expressed as mean ± SD (n = 3). Means with different lowercase letters a, b, c, are significantly different (P < 0.05).

Table 2.
Proximate composition of fresh and roasted plantain.

Test sample	Potassium mg/100 g	Magnesium mg/100 g	Vitamin B6 mg/100 g
Fresh plantain	240.70[a]	111.35[a]	0.21[a]
Electric	309.43[b]	119.21[b]	0.26[b]
Gas	305.75[c]	119.87[b]	0.25[c]
Charcoal	312.10[d]	120.39[b]	0.27[d]

Means with different lowercase letters are significantly different ($P < 0.05$), $n = 3$.

Table 3.
Analysis of selected micronutrients in fresh and roasted plantains.

Oil	Groundnut	Corn	Soya
Weight of cup (g)	44.95	44.95	43.56
Weight of samples (g)	2	2	2
Weight after extraction (g)	45.44	45.36	43.99
Weight of oil (g)	0.49	0.41	0.43

Table 4.
Fat uptake of chin-chin after frying using electricity.

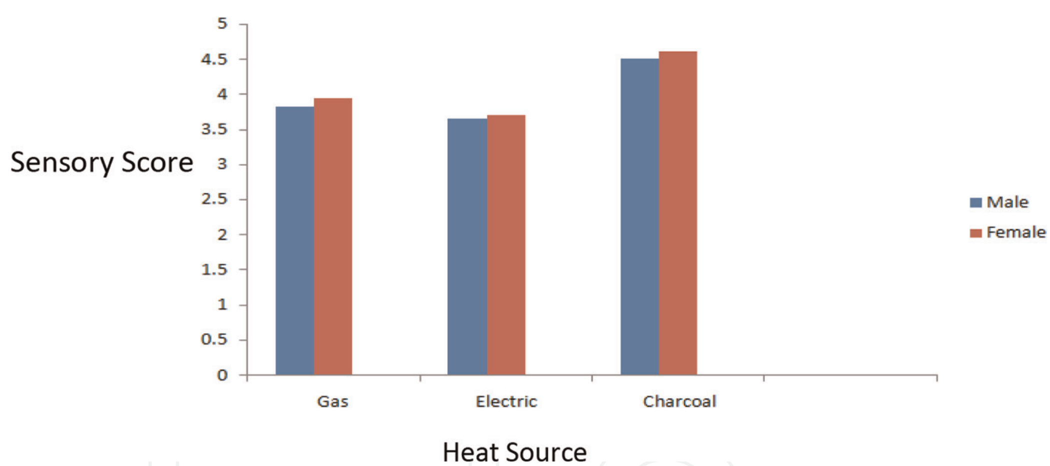

Figure 4.
Effect of roasting method on sensory attributes of plantain.

evaluation of the products (**Figure 4**) showed the preference of the panelists for the charcoal-roasted plantain, perhaps because gradual roasting influenced by prolonged residence time using the charcoal heat source produced the sweetest smelling flavor found the most acceptable in the product. The changes in selected micronutrients of the fresh and roasted products, namely, potassium, magnesium, and vitamin B6 are also presented (**Table 3**).

The sensory results showed a trend of higher scores from female panelists compared to males, suggesting a higher sensory acuity of the female panelists.

1.2 Frying

Deep-fat frying has been employed for centuries. Dogan et al. [18] noted that the Latin and Greek words for "frying" originated from the word "roasting," suggesting that frying may have developed from roasting. Today, it is an extremely popular technology employed in various kitchens all over the world and in about 85% of food service establishments for cooking chicken, fish, breaded vegetables, specialized pastries, French-fried potatoes, and other foods.

The simplest traditional process of deep-fat frying uses a kettle of oil heated on a stove or over an open fire in which small portions of the food are immersed in hot oil and removed when fried as determined by the experience of the cook. However, the first real breakthrough in the technology was the introduction of a continuous cooking process, which involves the immersion of the food in hot oil or fat for a specified period, followed by draining, cooling, and further processing or consumption [19].

The cooking medium during frying is the hot oil, also known as shortening, frying compound, or fat. The quality of the final food product largely depends on the quality of the oil. During the frying process, the inner moisture in the product is converted to steam, creating a pressure gradient. The surface dries out, causing the oil to adhere to the product surface and enter the surface of the damaged area [20]. Many factors have been reported to affect oil absorption in fried foods [21], including the quality and composition of the oil, temperature, time, product composition, moisture content, shape, porosity, pre-frying treatment, surface treatment, initial interface tension, and crust size [21].

The type of frying fat influences the quality of the finished product in terms of flavor, texture, shelf life, and nutritional attributes. Oils that have been exposed to a high temperature when left in the open air are subject to thermolytic and oxidative reactions [22]. These result in their partial conversion to volatile chain-scission products, nonvolatile oxidative derivatives, and dimeric, polymeric, or cyclic substances.

This is why the quality of fried foods depends not only on the type of food and frying condition but also on the nature of the oil used for frying. Selection of a stable frying oil is therefore of great importance in maintaining minimum product deterioration during frying and consequently a high-quality of the fried product [23].

Heating of the oil aids heat transfer by conduction and convection, the latter being caused by free water boiling at the surface upon immersion of the moist food in the hot oil. The moisture vaporizes and creates a path known as capillary pore, through which hot oil enters the food. The influence of oil uptake in this reaction is significant, with crust formation, shrinkage, and swelling occurring, thus inducing macro- and microstructural changes. This influences the vapor and liquid diffusion and safety assurance, and yields final products with the taste and textural characteristics expected by the consumer.

Typically, deep-fat frying is conducted at temperatures ranging from 120 to 180°C [24]. It is a complex process that involves simultaneous heat and mass transfer. It induces a variety of physicochemical changes in both the food and the frying medium. The principles underlying the mechanisms of oil absorption and water evaporation have been shown to be intimately related [25].

In fact, an extensive review of recent developments in the use of innovative methods for efficient frying of foods has been reported [26].

Various prototypes of deep fat fryers have been developed, including open fryers. These have been either single heat or double heat sources. Pressure fryers have also been designed to retain the vapor inside the fryer while cooling. The frying vessel captures the steam from the cooked food and increases the internal pressure until no more moisture is released from the food. The pressure usually ranges from 34473.80 to 82737.12 N/m^2 [20]. At such high pressures, it is not surprising that deep-fat fried products retain more flavor, and this constitutes a significant reason why they are widely popular across the globe. However, there are many areas where the energy source available may only be gas or charcoal; hence, the concept of a triple heat source has been developed in this study [15, 25].

1.2.1 Methodology

The desire for a deep-fat frying process equipment that is more user-friendly, efficient, and versatile led to the development of a simple, low-cost, and affordable multi-heat source deep fat fryer. Ogunmoyela et al. [8] reported the design and development of the multi-heat source deep fat fryer and its performance characteristics, as well as the methodology for determining oil uptake and vitamin A retention in the products, which are summarized below.

1.2.1.1 Design development and component characteristics of the multi-heat source deep fryer

The design, fabrication, and performance evaluation, including the major components as well as the controls of the fryer, have been described in detail in the literature studies [15, 25] and are as shown in **Figure 5**. The plain and front views, as well as the pictorial representations of the deep fat fryer, are also shown in **Figures 6–8**, respectively.

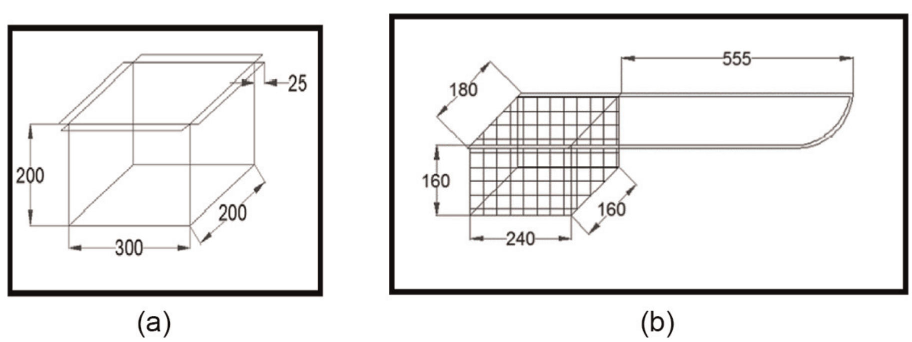

Figure 5.
Major components of the machine. A: Stainless steel frying pot, and B: stainless steel frying basket.

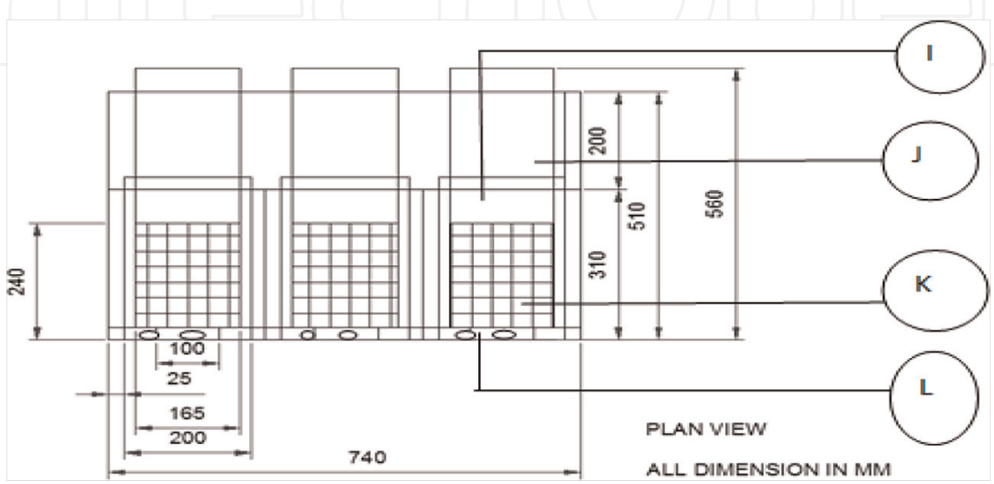

Figure 6.
Plain view of the machine. I: Stainless steel pot, J: basket lifter, K: stainless steel basket, and L: hinges.

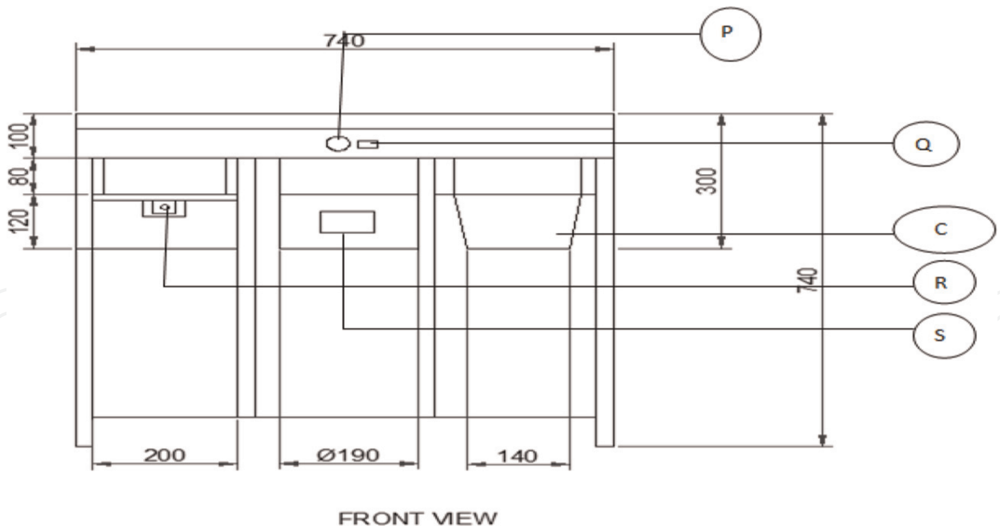

Figure 7.
Front view of the machine. P: Thermostat, Q: fan switch, C: charcoal compartment, R: gas control, and S: electric hot plate.

Figure 8.
Pictorial representation of the multi-heat source deep fat fryer (MSDFF).

The frame is divided into three rectangular but equal sections to facilitate a standing support to the pot hinged to the frame and connected to the frying pot for easy swing movements. The rectangular-shaped frying pot is made of stainless steel and sits on the frame. It can easily be removed for cleaning, while the frying basket is of the same shape, also made of stainless steel but smaller than the frying pot for free movement when hinged, apart from the need to allow free movement of hot air by convection.

The electric plate has a power of 1500 watts and is fitted with a sensor to detect changes in temperature, while the gas burner is welded to the frame support for the electric radiation plate. When the set temperature is attained, it cuts off automatically and vice versa. The charcoal compartment is also designed in this case to have a load-bearing capacity of 2 kg of charcoal for heating the fryer.

The fryer was developed using low-cost, locally available materials for affordability, at a total overall cost of about N50,000 (ca.$150.00) only but ensuring stainless steel for all contact surfaces to enable easy cleaning and to prevent corrosion and contamination.

The machine design considered the need for easy assembling, dismantling, adjustment, and operation, as well as the safety of the operator in the positioning of the various component parts. With a power requirement of 1.43 Kw, it is designed to be minimally efficient for processing any type of food material using good quality frying oils.

1.2.1.2 Performance Characteristics and Validation

The multi-heat source deep fat fryer was designed to use multiple heat sources, namely, charcoal, gas, and electricity, as sources of energy tested in different frying oils, namely, groundnut, soya, and corn oils. Heat is driven by conduction during deep-fat frying in the medium in line with the second law of thermodynamics. It is transmitted into the oil by convection and by conduction into the interior of the food. Part of it also escapes to the atmosphere by radiation since the process usually occurs in an open system.

The performance of the fryer was tested using wheat flour, sugar, eggs, baking powder, salt, and margarine mixed into a dough and fried with the different oils to obtain different products. Performance in each of these oils was tested using the different heat energy sources, namely, charcoal, gas, and electricity, respectively.

The fryer was successfully tested and validated in deep-fat frying of fried wheat flour chips, known as *chin-chin*; wheat flour balls known as *puff-puff*; as well as plantain chips, bean flour, and yam chips.

1.2.2 Performance Measurements and Process Chemistry

Deep-fat frying is a complex process that involves simultaneous heat and mass transfer. The process induces a variety of physicochemical changes in both the dough and the frying medium. As foods are hygroscopic and carry significant quantities of bound water in their porous matrices, the water diffuses from the matrix during frying, creating pathways usually referred to as “capillary pores.” The formation of these capillary pores enhances oil absorption. As the food is fried, the moisture is converted to steam and released under pressure.

The type of product, process, and intensity of heating, coupled with the initial moisture content of the food product influences the final pore structure. Various studies have reported that the relationship between moisture loss and fat absorption is proportional and linear [27]. The diffusion rate of the moisture into the fat and that of the fat through the capillary pores depend on the temperature gradient across the heating medium. Since the two are proportional to one another, the basic equation for mass flux is applicable.

The mechanisms of water evaporation and oil absorption have been well described in the literature. As the product is immersed into the hot oil, the initial fat absorption takes place through surface wetting, by capillary action. As the product heats up, moisture is converted to steam, migrating to the surface and eventually into the frying medium due to a pressure differential. The vapor being released from the dough surface impedes the intrusion of fat into the product during surface boiling. Thus, the color of the dough gradually changes to brown (**Figure 9**) with heat conduction by the frying pot, transfer by convection within the hot oil, conduction into the interior of the food, as well as radiation heat losses.

The capacity of the machine using groundnut, corn, and soya oils (**Figure 10**) was found to be 6.90, 8.50, and 7.68 kg/h using electricity as the energy source; 8.50, 8.60, and 8.46 kg/h using gas as an energy source; and 5.60, 6.80, and 5.60 kg/h with charcoal as the energy source. From these results, the conductive heat requirement of the machine was found to be 1428 W, while the heat required for effective frying was 1392 W, and heat loss by radiation was only 36 W.

The results of the fat uptake (**Tables 4–6**) of the *chin-chin* fried with the fryer, using different compartments of electric, gas, and charcoal energy sources, respectively, are also presented.

The *chin-chin* fried with corn oil gave the least fat uptake followed by the soya oil when using gas. Corn oil also gave the highest vitamin A retention (**Figure 11**) given

Figure 9.
F: Gradual changes during frying operation; G: chin-chin produced ready for packaging.

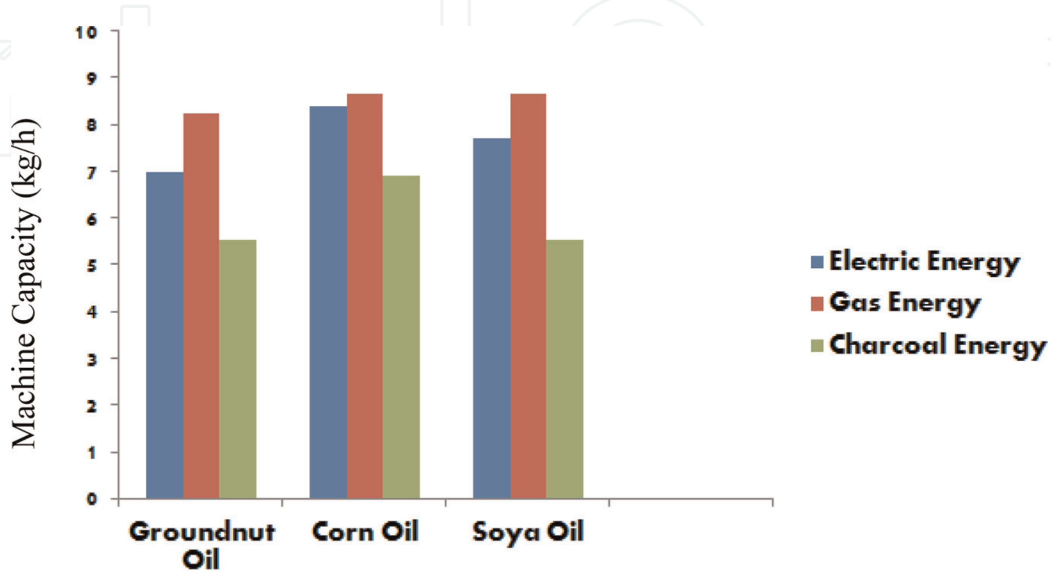

Figure 10.
Machine capacity (kg/h) using different oils and different heat sources.

Oil	Groundnut	Corn	Soya
Weight of cup (g)	44.43	44.71	44.83
Weight of samples (g)	2	2	2
Weight after extraction (g)	44.94	45.17	45.30
Weight of oil (g)	0.51	0.46	0.47

Table 5.
Fat uptake of chin-chin after frying using gas.

Oil	Groundnut	Corn	Soya
Weight of cup (g)	44.82	44.96	44.83
Weight of samples (g)	2	2	2
Weight after extraction (g)	45.49	45.53	45.46
Weight of oil (g)	0.67	0.57	0.63

Table 6.
Fat uptake of chin-chin after frying using charcoal.

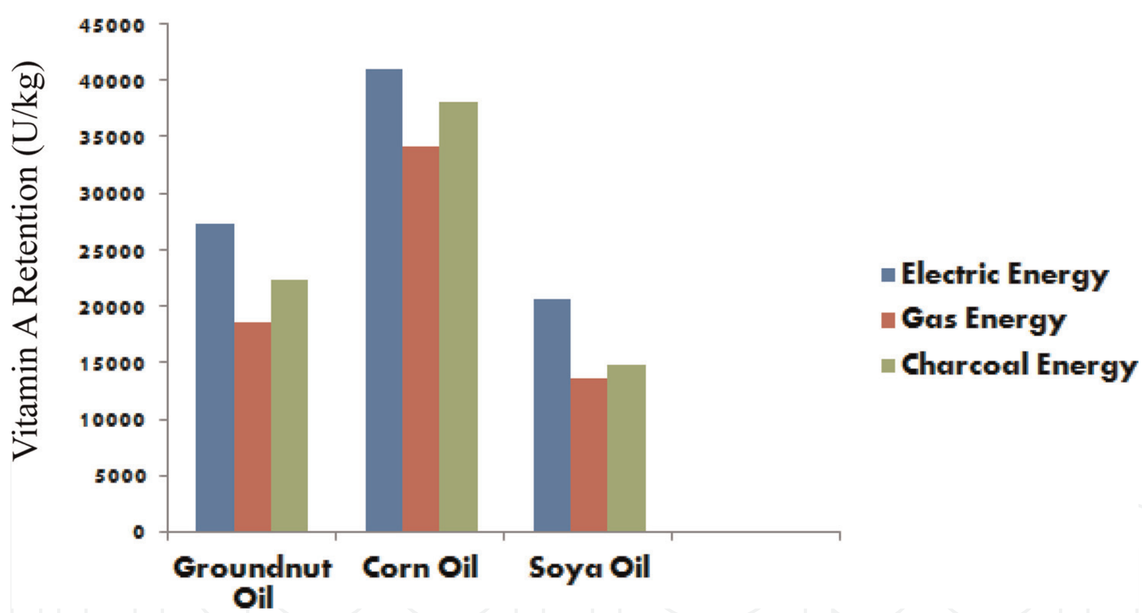

Figure 11.
Vitamin A retention in chin-chin during frying using different heat sources.

the mandatory vitamin A level of 3000 IU/kg in flour and 2000 IU/kg in vegetable oils under the National Food Fortification Programme in Nigeria.

Given the implications of high fat intake on the increasing incidences of cardiovascular diseases, the figures obtained here indicate the significant promise of the use of this equipment in the control of fat uptake in deep-fat fried products.

1.3 Smoking

Smoking is the practice or process of seasoning, to preserve food either by exposing it to smoke from a burning or smoldering substance, usually wood, or by cold smoking at a reduced temperature of 12–25°C. This is to impart flavor and ensure the adequacy of preservatives added to the product. Smoking can also be done by bringing food into contact with vaporized liquid smoke. In many African countries, smoking is the most significant method for preserving fish and wildlife. Wood smoke is made up of a variety of organic chemical components, some of which have antibacterial properties [28]. When wood smoke is condensed into water, it produces liquid smoke, which can be utilized for food smoke flavoring. The dangers associated with the illegal use of chemically preserved wood are one of the concerns associated with smoked foods, and this is why gas systems have been advocated in recent years by developed countries. In fact, the current trends of using green technologies in food production and processing have been reported [29]. In particular, a recent review has shown the technological advances in Ghana which led to the development of such smoking methods as the FAO-Thiaroye technique of processing (FTT), and Abuesi gas fish smoker for fish smoking and drying, with results of lower PAH4 levels and uniform appearance of end products [30]. However, there is no doubt that wood-smoked foods are still preferred in many developing countries of the world, and they are safe if they are made from fresh raw materials that are free of natural toxins, chemical pollutants, pathogens, and parasites; and if the storage conditions do not promote microbial proliferation or toxin production [31]. In addition, the sensory characteristics of such products are usually more intense and better than those of gas-smoked products.

Thus, there is no doubt that smoking is a unit operation that has gained overwhelming acceptance across the globe. But the conventional methods for smoking are often laborious, stressful, and unhygienic, thus posing health risks to processors. Based on these limitations, more modern, low-cost, and effective smoking kilns suitable for small- and medium-scale quality production of fish and meat have been investigated in various studies.

Smoking is a combination of salting, drying, and heating of fishery products. The regulation of physicochemical parameters such as pH, VBN, TBARS, fatty acid content, and texture profiling using the smoking preservation process increases sensory quality, allowing for longer storage times of high-quality fish products. Smoking of the food considerably slows down oxidative changes and prevents microbial growth. When smoke from incomplete combustion of wood or sawdust is deposited on the surface of processed fish, volatile chemical compounds are released, which help to suppress bacterial growth [32]. Due to the unique color and flavor, smoked items have a high demand among consumers. It has been reported that smoking of wood or sawdust releases a variety of complex chemicals such as phenols, ethers, esters, hydrocarbons, acids, alcohols, and ketones, which are responsible for the subsequent color and flavor development [33].

Smoking has also been classified into three types based on temperature: cold (12–25°C), warm (25–45°C), and hot (40–100°C). The type of heating procedure selected is critical to product quality. However, heating can promote protein denaturation in such products, resulting in reduction of both nutritional and functional qualities. To obtain a premium-grade smoked product, optimizing the time, temperature, and sawdust material in the hot smoking procedure has therefore been shown to be vital [34]. Sensory evaluation (color, texture, odor, flavor, and overall acceptance), physicochemical assessment (pH level, VBN level, TBARS level, and TMAO and fatty acid content), and microbial growth are also important parameters for establishing the qualities of smoked fish products [34]. Many smoked products have, however, been found to be mutagenic and carcinogenic due to polycyclic aromatic hydrocarbons (PAHs) found in wood smoke. In recent years, wood-smoked foods have been increasingly investigated for potential genotoxicity and carcinogenicity. However, it has been reported that PAHs are processed by enzymes in the human body, resulting in premutagenic and carcinogenic DNA adducts [35, 36]. Nevertheless, it is important to stress that these concerns are associated with improperly wood-smoked products, which is why the smoking process requires standardization, rather than being discarded as has been advocated in some developed countries.

In many regions of the world, fish processing *via* hot smoking or kiln has been practiced for centuries. In fact, smoked fish is one of the most popular delicacies in many developing countries, with various types of smoking kilns ranging from traditional open-fire to mud-brick and cylindrical drums.

Despite this fact, the absence of suitably controlled process has long been a challenge to the quality of smoked fish from many developing countries. Locally accessible technologies like mud bricks, stone, and firewood are commonly employed, but with negative impact on the quality of the finished product. The market value of the product declines due to smoke damage and unappealing appearance of processed fish, while standard conditions for quality assurance and hygiene remain a challenge [37].

To reduce the stress, drudgery, and health risks to processors associated with the conventional methods of smoking, a low-cost and effective smoking kiln suitable for small- and medium-scale quality production of fish and meat was developed and evaluated.

1.3.1 Design characteristics of low-cost smoking kiln

The smoking kiln is a double-jacketed cabinet with a thickness of 15 mm. It is made from mild steel and lagged with a fiber glass insulator purposely to prevent heat loss to the environment during smoke drying. The smoking chamber consists of set trays arranged into three rows and a smoking rack with the same length and breadth. The overall dimension of the cabinet is $600 \times 515 \times 650$ mm, and the dimension of the trays is $425 \times 325 \times 150$ mm. The fabrication and assembly of the smoking kiln was done at our Mechanical Engineering workshop of Bells University of Technology, Ota, Nigeria.

The trays have a trough fabricated to their ends to allow for a flow out of food product drippings during smoking without accumulation. This trough is connected to a pipe that runs from the top to the bottom at the back of the smoking kiln through which the troughs of the other trays connect, collecting all product drippings and expelling them to the outer part of the smoking kiln. The heat source of the smoking kiln is charcoal, which is contained in two pots, each with a dimension of $484 \times 120 \times 70$ mm, placed by the sides of the rack system that carries the trays.

The design allows for air circulation by convection in the combustion chamber with heated air carried in all directions of the loaded trays, and air inlets at the lower front of the smoking kiln facilitate the flow of heat. The chimney is fitted with an adjustable valve that controls the heat buildup within the smoking kiln and conducts the smoke to the external environment. The isometric and orthographic projections of the smoking kiln assembly (**Figures 12** and **13**) are presented below.

The machine was designed with a tray arrangement at the center of the kiln, to allow for proper air circulation *via* an indirect mode of heating. The region between the charcoal pots was perforated to allow the inflow of fresh air to support the combustion and mobility of smoke in the kiln. A tray system slightly sloped backward was adopted to allow oil leaching from product flow into a trough where it is collected.

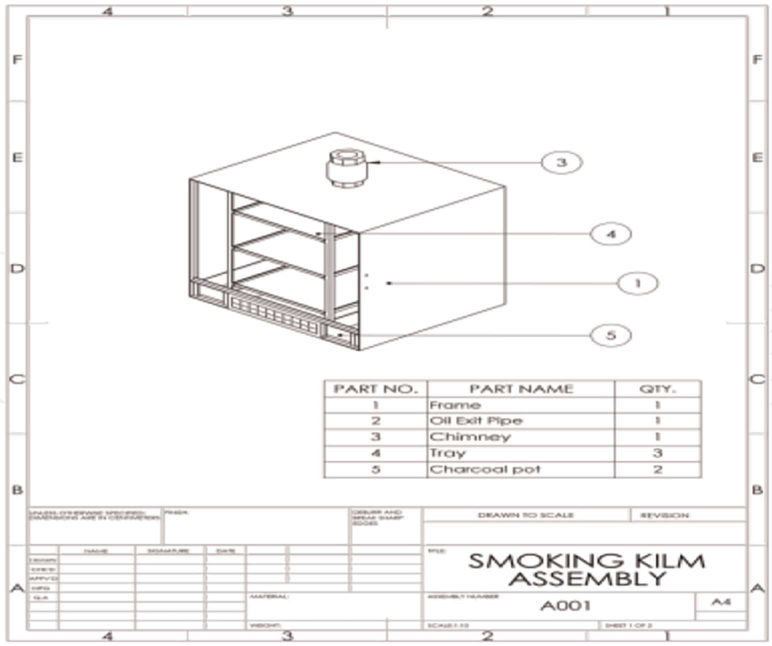

Figure 12.
Isometric projection of smoking kiln assembly.

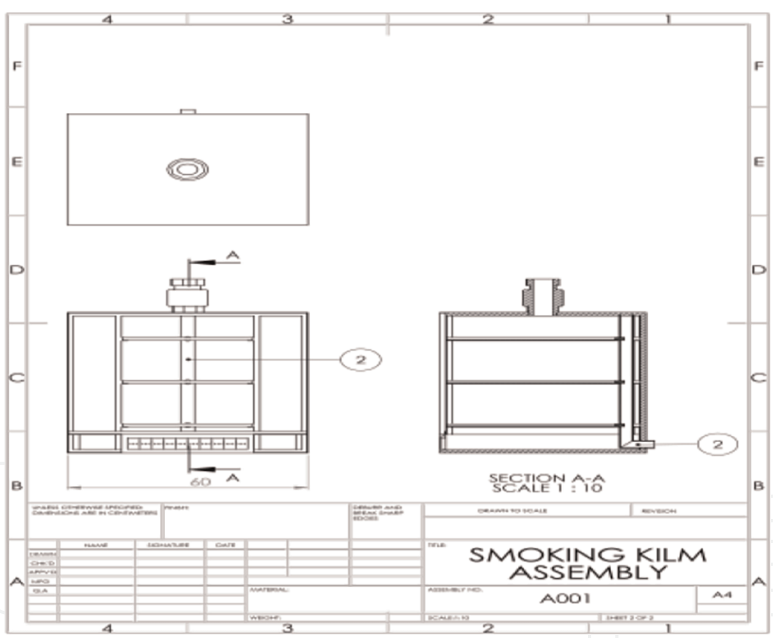

Figure 13.
Orthographic projection of smoking kiln assembly.

1.3.2 Design calculations

Volume of the fish tray (VT) is calculated as:

$$VT = l \times b \times h \tag{9}$$

where l = length of the tray = 42.5 cm, b = width of the tray = 32.5 cm, and h = height of the tray = 150 cm

Volume of the charcoal pot (VC): is calculated as:

$$VC = l \times b \times h \tag{10}$$

where l = length of charcoal pot = 48.4 cm, b = width of charcoal pot = 12 cm, and h = height of charcoal pot = 7 cm.

Determination of heat transfer by conduction, convection, radiation, and thermal resistance is in accordance with Ref. [38].

Heat transfer (q) by conduction is obtained as:

$$q_{cond} = \frac{-KA(T_2 - T_1)}{l} \tag{11}$$

where K = thermal conductivity of the material (45 W/m °C), A = area of the fish tray (0.41 m^2), l = thickness of fish tray (0.0015 m), T_1 = temperature of the inside smoking kiln (280°C), T_2 = temperature of the inside smoking product (90°C), while negative sign of K is to take care of the decrease in temperature along the direction of heat flow.

Heat transfer (q) by convection is obtained as:

$$q_{conv} = hA\left(t_s - t_f\right) \tag{12}$$

where h = coefficient of convective heat transfer (free convection) (20 W/m^{2}°C), A = area of the charcoal pot (0.12m^2), T_s = surface temperature (280°C), and T_f = fluid temperature (90°C).

Heat transfer (q) by radiation is obtained as:

$$q_{rad} = F\delta A\left({T_1}^4 - {T_2}^4\right) \tag{13}$$

where F = emissivity coefficient of mild steel (0.20), δ = Stefan Boltzmann's constant (5.67×10^{-8}), A = area of the charcoal pot (0.12 m^2), T_1 = temperature of the inside smoking kiln (553 K), and T_2 = temperature of the outside smoking kiln (303 K).

Heat capacity q_{total} of the machine is obtained by:

$$q_{total} = q_{cond} + q_{conv} + q_{rad} \tag{14}$$

Value of thermal resistance is obtained by:

$$(R_{th})_{rad} = \frac{T_1 - T_2}{q_{rad}} \tag{15}$$

Heat required for smoking products:

$$q = M \times C_p \times \Delta T \tag{16}$$

where M = mass of sample in the smoking kiln at a time (fish = 5.20 kg, beef = 5.85 kg, and chicken = 8.20 kg), ΔT = change in temperature (°C), and C_p = specific heat capacity of products: fish = 3.60 kJ/kg°C, beef = 2.85 kJ/kg°C, and chicken = 3.22 kJ/kg°C [39].

The heat capacity q_{total} of the machine is given as 2337.57 kJ, and this exceeds the heat requirement for each of the products smoked: fish = 1123.20 kJ, beef 1000.35 kJ, and chicken = 1584.24 kJ.

1.3.3 Performance Evaluation of results

Heat capacity of the machine was calculated to be 2337.57 Kw, while the heat requirements for smoking fish, beef, and chicken were calculated to be 1123.20, 1000.35, and 1584.24 kJ, respectively. The rates of moisture removal (**Table 7**) in the smoking kiln were 25.87%/hr., 23.37%/hr., 28.05%/hr., and 24.51%/hr. for Atlantic mackerel, herring fish, beef, and chicken, respectively. Smoking temperature was determined to be 90°C, which was in accordance with the findings of Rahman [40] that the smoking temperature range suitable for effective drying is 80–90°C. It was observed that at the various tray levels of the smoking kiln, there was a slight temperature difference, probably due to hot air being of lighter density than cold air and floating upward. In the smoking kiln, since the heat source is not directly under the rack system, it floats to the upper part of the smoking kiln, and the products at upper tray dry faster. The performance results for different products are summarized in **Tables 7** and **8** below.

The results of the sensory evaluation of different products in the machine (**Table 8**) also showed that there was no significant difference ($p > 0.05$) except for the texture. Although there was no significant difference in overall acceptability of the samples, there was a clear preference for Atlantic mackerel fish. However, at 5% level of significance, panelists did not find any significant difference ($p > 0.05$) in the sensory attributes of the smoked products. **Figure 14** shows an exploded view of the kiln.

Samples	Time taken (hrs)	Initial weight (kg)	Final weight (kg)	Moisture loss (%)	Rate of moisture removal (%/hr)
Beef	2	5.85	2.57	56.10	28.05
Atlantic mackerel	2	5.20	2.51	51.73	25.87
Chicken	2	8.20	4.18	49.02	24.51
Herring fish	2	5.20	2.77	46.73	23.37

Table 7.
Machine evaluation.

Sample	Appearance	Aroma	Taste	Texture	Overall acceptability
SMBE	6.95 ± 1.36^{a}	7.35 ± 1.28^{a}	7.45 ± 0.83^{a}	7.10 ± 1.41^{a}	7.65 ± 0.88^{a}
SFTI	7.50 ± 1.10^{a}	7.75 ± 1.16^{a}	7.95 ± 1.00^{a}	8.10 ± 0.79^{ab}	8.00 ± 0.79^{a}
SMCH	7.07 ± 1.08^{a}	7.30 ± 1.30^{a}	7.50 ± 1.28^{a}	7.40 ± 1.47^{ab}	7.65 ± 1.04^{a}
SFSH	7.45 ± 1.28^{a}	7.50 ± 1.19^{a}	7.55 ± 1.19^{a}	7.45 ± 1.19^{b}	7.50 ± 1.15^{a}

SMBE: smoked beef, SFTI: smoked Atlantic mackerel fish, SMCH: smoked chicken, SFSH: smoked herring fish. Values are means ± standard deviation of duplicate determinations. The mean values of the samples within a column with different superscripts (letters) are significantly different ($p < 0.05$).

Table 8.
Sensory evaluation of smoked samples.

Figure 14.
Exploded view of the smoking kiln.

1.4 Fermentation

West African food cultures, like many other parts of the world, are rich in spontaneously fermented foods, the majority of which have been passed down from one generation to another. The fermentation process involves the conversion of starch or sugar into an alcohol or acid. This is the basis of several foods, including baked products. During the fermentation of wheat flour dough, for example, carbon dioxide is produced and trapped as pockets of air within the dough, causing the dough to rise. During subsequent baking, the carbon dioxide expands and causes the dough to rise further, with the alcohol produced evaporating during this baking step.

The fermentation of foods in West Africa is said to account for 40% of the population's diet, a percentage that increases with decreasing income. Africans usually ferment cereal-based foods such as sorghum, millet and maize; roots such as cassava; fruits; vegetables; and less commonly meat and fish [41]. Fermentation also covers leguminous plants and oilseeds, to produce fermented condiments that are used as flavorants in soups. Such fermented condiments include "*ogiri*" from castor bean (*Ricinus communis*), "*dawadawa*" from African locust beans (*Parkia biglobosa*), and "*ugba*" from African oil bean (*Pentaclethra macrophylla*).

One of the major advantages of fermentation is the enhancement of both nutritional and sensory quality of foods by the conversion of macronutrients such as proteins and sugars into easily digestible compounds and the development of flavour compounds. Fermented African locust bean seeds, for example, are a rich source of protein and consist of oil, dietary fiber, vitamins (vitamin B, riboflavin, and vitamin A) and minerals. The most common groups of microorganisms involved in food fermentation are bacteria, yeasts, and mold [42]. Spices and condiments are plant-derived substances (from dried seeds, fruit, root, bark, and leaves) used in minute quantities as food additives to stimulate flavor and taste in foods, beverages, and drugs; improve color; and in some cases, serve as preservatives [43] and overall sensory acceptability of foods. Condiments are applied in the form of a sauce powder to contribute calorie and protein intake and are generously added to soups as low-cost meat substitutes by low-income families [44]. Thus, the awareness of the benefits of eating food products with little or no chemical food additives or preservatives for healthy living and life expectancy is increasingly being promoted all over the world. This is why microbial fermentation technology has become such a promising, rapidly growing, revolutionary field involving the use of microbes for the production of compounds that are of immense use in the production of biofuels, pharmaceutical, environmentally friendly materials, energy, fine chemicals, and the food industry in the quest for a bio-based society, with an eye on the sustainability factor [45].

Foods prepared with chemical additives and preservatives are susceptible to chronic and noncommunicable diseases. Therefore, this global shift to naturally processed foods calls for indigenous food processing techniques that will guarantee consumer safety, healthy living, and storability. An example of recent developments in the packaging and commercialization of fermented African locust beans to cube form using a locally fabricated machine is presented in this chapter. The production and cubing of African locust beans using a prototype cubing machine fabricated in the Mechanical Engineering Workshop of Bells University of Technology, Ota, in Nigeria is described below.

Using the traditional fermentation process, the dried locust beans are inspected, and removal of immature seed and broken and damaged locust beans takes place to avoid poor quality and unsafe finished products. Prewashing is done before the locust beans are placed in clean pots. They are then allowed to boil for 6 hours so as to partially de-shell the locust beans. The boiled locust beans are then drained and allowed to cool for easier mashing. The cooled locust beans are placed in the mortar and hand-mashed with the addition of potash. The de-shelled locust beans are thereafter hand-sorted, washed with water and placed in a calabash containing washed banana leaves, and then allowed to ferment for 24 hours. In order to facilitate the fermentation process, a little amount of salt is added. The locust beans are then dried using hot air oven at 60°C for 24 hours to reduce the bulkiness by 29%. The dried locust beans ware dry-milled with using a hammer mill, and the resulting milled locust beans are sieved to obtain a homogenous size.

The locust beans' powder is then divided into two equal parts. One of them is subjected to cubing using the prototype cubing machine with addition of lecithin to serve as the binding agent in ratio 3:1 (locust bean powder: lecithin). The powdered and cubed locust beans are then packaged for further analyses. In the design of prototype cubing machine, various factors were considered in the selection of material, including material availability, suitability, durability, and cost of materials to meet the desired quality performance. The process flow diagram for the production of fermented, dried, and cubed African locus beans is shown (**Figure 15**) below.

1.4.1 Prototype cubing machine design

The major components of the prototype machine (**Figure 15**) are u-beam, cubing unit, mold, cylinder, and the frame. The u-beam made from mild steel was cut and shaped into 1500 mm × 210 mm × 26 mm; the cubing unit consists of cutting blade made from stainless steel and a cylinder spring and handle; the mold houses the blade and is made from stainless steel with dimension 110 mm × 100 mm × 21.5 mm and capable of producing 200 cubes per hour; the cylinder consist of iron rod that is

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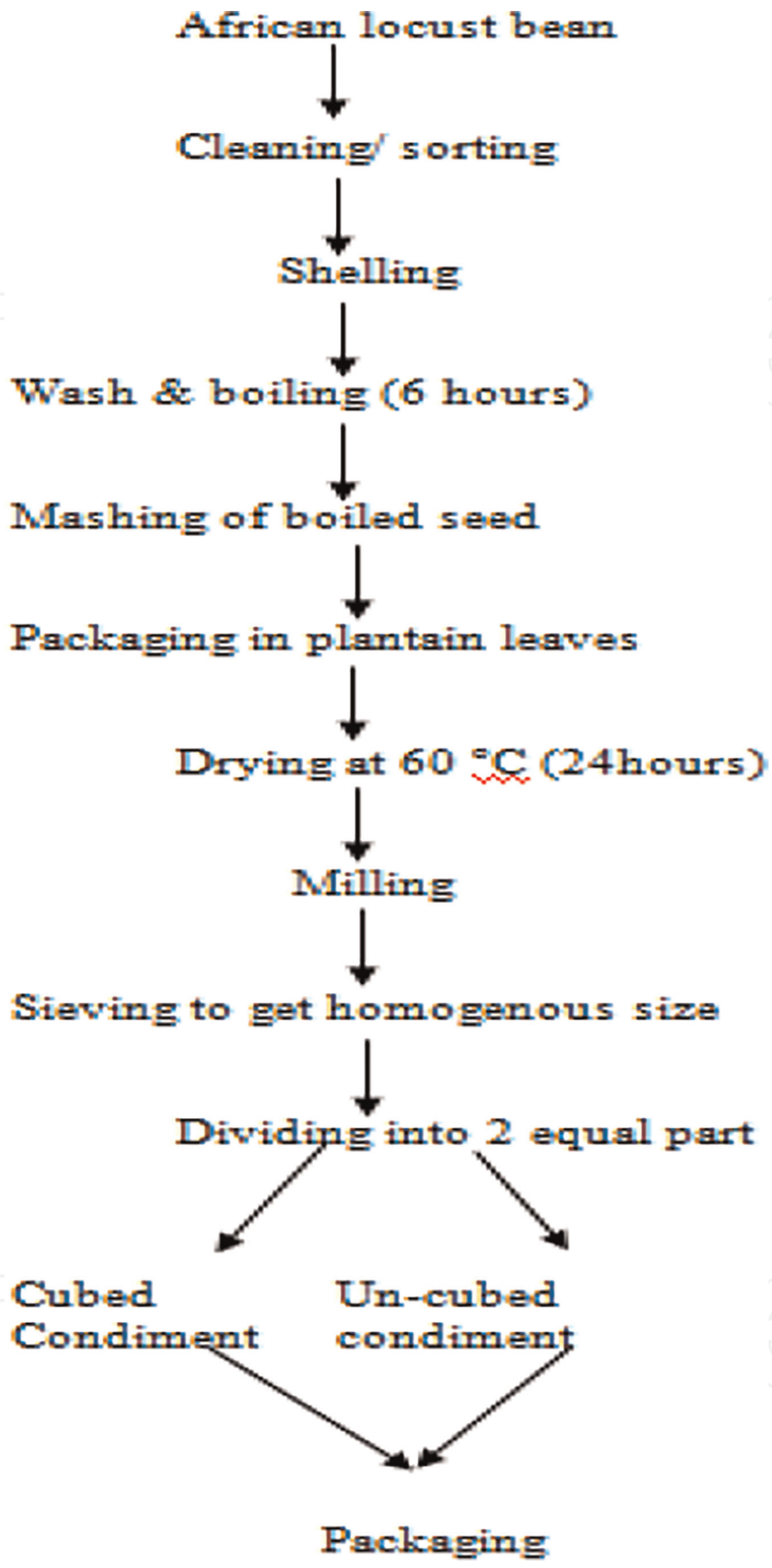

Figure 15.
Flow diagram for the production of fermented, dried, and cubed African locust beans.

10 mm tall and 2 mm in radius and made from mild steel. The outer part of the cylinder is lined with flat metal connected to the handle, and as the handle moves downward, it presses the spring, while the mold is in contact with the condiment on the table to form cubes. The frame unit made from angle iron provides support to other components of the machine. The upper part of the frame is the working table

Figure 16.
Snapshot of the prototype cubing machine.

that has direct contact with food made from stainless steel. The snapshot of the machine is shown below in **Figure 16**.

1.4.2 Design calculations and performance evaluation

The design analysis for the spring support (**Figure 17**), power requirement (**Figure 18**), machine capacity, and efficiency are considered as follows:

Selected design data are as stated:

Spring free length, L = 120 mm, Diameter of the wire, d = 2.5 mm, Number of active coils, N = 14, Diameter of the coil, D = 28 mm, Mass of the handle, m = 170 g, Mass of the connecting rod = 550 g, Allowable stress (δ_s) induced in the spring due to twisting for industrial spring = 6.25×10^5 Nm^{-2} [46].

The compression load of the spring, F was obtained using the relationship reported [47].

$$F = \delta_s 2\pi r L \tag{17}$$

where r = $\frac{d}{2}$.

$$F = 6.25 \text{ x } 10^5 \text{ x } 2 \text{ x } \frac{22}{7} \text{ x } 0.00125 \text{ x } 0.12.$$

F = 589 N.

Selected weight of the handle,

$$W = mg. \tag{18}$$

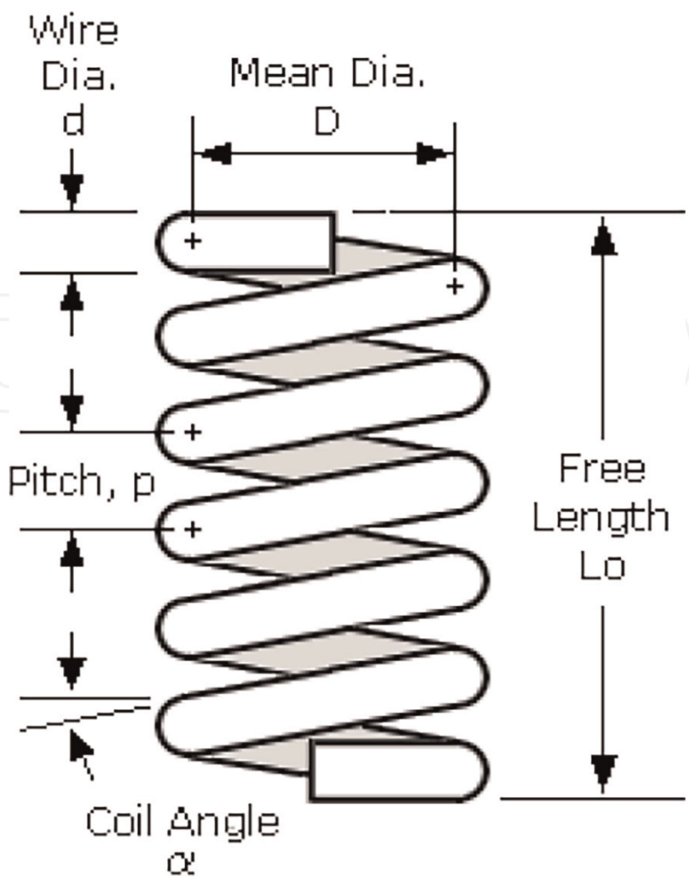

Figure 17.
Design for spring support.

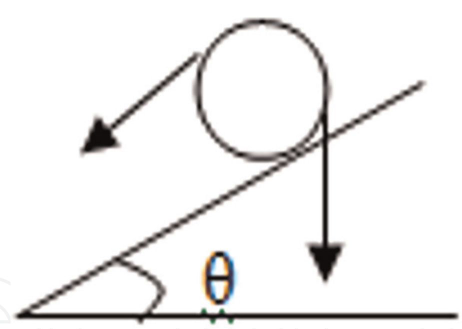

Figure 18.
Design for machine power requirement.

where m is the mass in kg, and g is the acceleration to gravity.

Therefore, W = 0.170 × 9.81.

W = 1.67 N.

Machine compressive force,

$$F_s = F + W \tag{19}$$

F_s = 589 + 1.67.

F_s = 590.67 N.

The maximum deflection of the spring, E was obtained from the relationship given in Ref. [48].

$$L - E = (n + 2)d \tag{20}$$

where n is the number of active coils.

E = 0.12 – E = (14 + 2) 0.0025.

E = 80 mm.

Therefore, the maximum deflection of the spring is 80 mm.

The torque T required to overcome friction in spring was obtained using the relationship as stated in Ref. [47].

$$T = \frac{\pi \delta_s d^2}{16K} \tag{21}$$

where K is stress concentration factor = 1.225.

$$T = \frac{\frac{22}{7} \times 6.25 \times 10^5 \times (0.0025)^2}{16 \times 1.225}$$

T = 0.63 Nm.

Therefore, the torque require to overcome friction in spring is 0.63 Nm.

Stiffness of spring was obtained from the relationship given in Ref. [46].

$$\sigma = \frac{\pi R^4 G}{2L} \tag{22}$$

where σ = stiffness of spring in Nm^{-1}.

R = radius of coil in m.

G = mild steel modulus of rigidity = 8.2 x 10^6 Nm^{-2} [49].

$$\sigma = \frac{\frac{22}{7} \times (0.014)^4 \times 8.2 \times 10^6}{2 \times 0.12}$$

σ = 4.13 Nm^{-1}.

Therefore, stiffness of the spring is 4.13 Nm^{-1}.

$$\mu = \mathrm{Tan}\theta \tag{23}$$

where μ is the coefficient of friction, and θ is the angle of deflection

$$\mathrm{Tan}\theta = \frac{x}{y} \tag{24}$$

where x is the maximum compressive force, and y is the weight of handle + weight of connecting rod.

$$\mathrm{Tan}\theta = \frac{590.67}{1.67 + 5.40}$$

$$\mathrm{Tan}\theta = 83.55$$

$$\theta = \mathrm{Tan}^{-1} 83.55$$

$$\theta = 89^o$$

To calculate angular speed, S

$$S = \frac{r\theta}{t} \tag{25}$$

where θ is in radian, r is the length of plate base = 100 mm, and t is the time of deflection = 1 second.

$$S = \frac{0.1 \times 89\pi}{180}$$

S = 0.16 ms^{-1}.

To calculate machine power requirement for cubing, P

$$P = F_s S \tag{26}$$

P = 590.67 × 0.16.

P = 94.51 W.

Conclusively, the power required by the machine for effective cubing falls within sustainable human potential power is 70–500 W.

Design for machine efficiency

$$Efficiency = \frac{Output}{Input} \times 100 \tag{27}$$

During machine evaluation, five batches in triplicate were carried out, and average value for each batch was recorded (**Table 9**). The weight of the cubes was determined by analytical weighing balance, and time taken for each experiment was taken using a stopwatch.

Machine capacity is calculated as follows:

$$Capacity = \frac{N}{t} \tag{28}$$

where N is the number of cube produced, and t is the time taken in the production.

Average machine capacity = 191 cubes/hr.

Input (g)	Output (g)	Eff. (%)	Number of cube produced	Time taken (sec.)
500	422	84.40	84	1500
400	358	89.50	72	1320
350	326	93.14	65	1200
300	290	96.67	58	1110
250	246	98.40	49	1020
Average machine efficiency = 92.42%.				

Table 9.
Machine performance evaluation.

1.4.3 Product weight control

The weights of fermented African locust bean cubes produced were found to be slightly different from one another even from the same batch production. This variation could be from the mixing or machine settings among others, and further improvements in machine performance are possible with the investigation of the actual cause of the problem using appropriate statistical control chart design.

Procedure for $\overline{\overline{x}}$ control chart

Below is the step-by-step procedure to determine the control limit using $\overline{\overline{x}}$ chart

i. Draw a sample $\{x_1, x_2, x_3, \dots \dots \dots \dots x_k\}$ of size k at a stage of the production process.

ii. Repeat (i) for n samples at equal intervals of time.

iii. Calculate the sum $\sum x$ for each sample.

iv. Calculate the mean $\overline{x} = \frac{\sum x}{k}$ for each sample.

v. Calculate the mean of the mean () in (iv) for all observations where $\overline{\overline{x}} = \frac{\sum -x}{n}$.

vi. Calculate the variance $s^2 = \frac{\sum (x - \overline{x})^2}{k}$for each sample.

vii. Calculate the standard error (S) for every S^2 in (vi)

viii. Calculate the mean $-s = \frac{\sum s}{n}$ for all standard errors in (vii)

ix. Obtain the control limit for x as follow:

a. $\overline{\overline{x}}$ - Central control limit.

b. $\overline{\overline{x}} + \frac{3\overline{s}}{\sqrt{n-1}}$ - Upper control limit.

c. $\overline{\overline{x}} - \frac{3\overline{s}}{\sqrt{n-1}}$ - Lower control limit.

Table 2 shows triplicate weight readings of cubed fermented African locust beans for each batch production as illustrated for the determination of the control limits.

From **Table 10**,

$$\overline{\overline{x}} = 5.012$$

$$\overline{S_i} = 0.0162$$

Control limits:
Central control limit = 5.012.
Upper control limit = 5.024.
Lower control limit = 4.989.

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Batches	Cube weight (g)						
	1	2	3	$\sum x_1$	$\bar{x}$	s^2	S
1	5.01	5.02	5.03	15.06	5.02	6.70×10^{-5}	0.0082
2	4.98	4.99	5.03	15.00	5.00	4.67×10^{-4}	0.0216
3	4.99	5.02	5.04	15.05	5.02	4.33×10^{-4}	0.0208
4	4.98	5.00	5.02	15.01	5.00	2.67×10^{-4}	0.0163
5	5.01	5.01	5.04	15.06	5.02	2.00×10^{-4}	0.0141
					25.06		0.081

Table 10.
Statistical control of batch production of fermented, dried, and cubed African locust beans.

1.4.4 Performance evaluation results

For the machine design analysis, some parameters were selected, while some were calculated using mathematical relationships. Those that were calculated are: compression load of the spring, F = 589 N; machine compressive force, Fs = 590.67 N; maximum deflection of the spring, E = 80 mm; torque, T = 0.63 Nm; stiffness of the spring, σ = 4.13 Nm^{-1}; angle of deflection of the machine, Θ = 89°; the angular speed of the machine, S = 0.16 ms^{-1}; machine power requirement, P = 94.51 W; average efficiency of the machine = 92.42%; and the average capacity of the machine = 191 cubes/hour. However, as the input of the machine increased from 250 to 500 g, the efficiency also decreased from 98.40 to 84.40%, while machine capacity increased from 175 cubes/hr. to 200 cubes/hr.

This means that the higher the input, the longer is the residence time and the rate at which efficiency drops, implying that more losses could be incurred. From the cube control chart (**Figure 19**), it is evident that in all the batches, the production process is

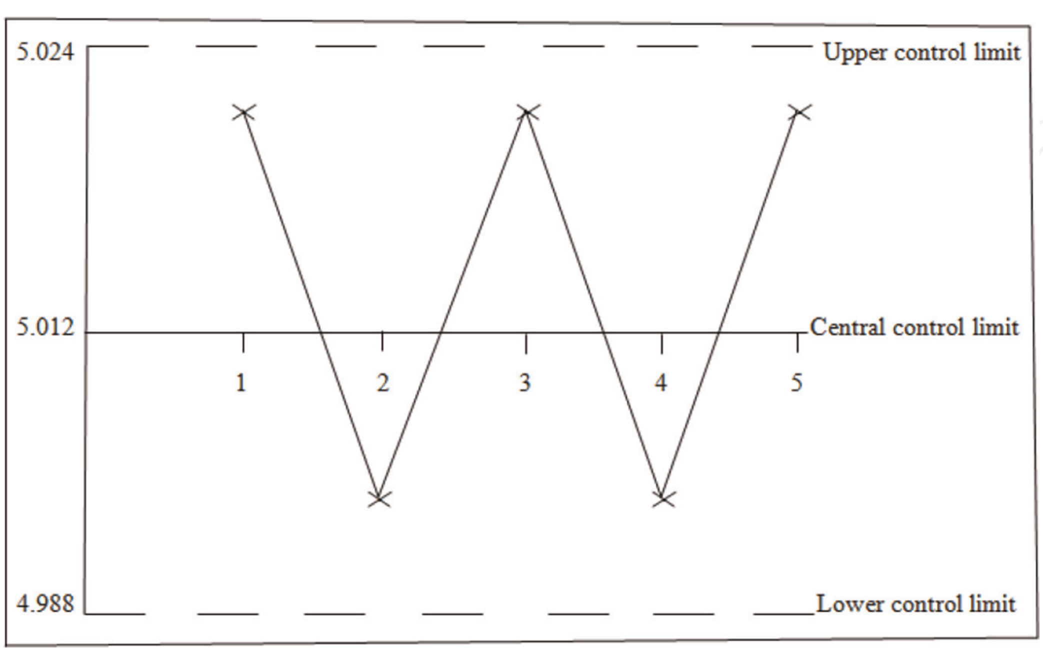

Figure 19.
Production control chart.

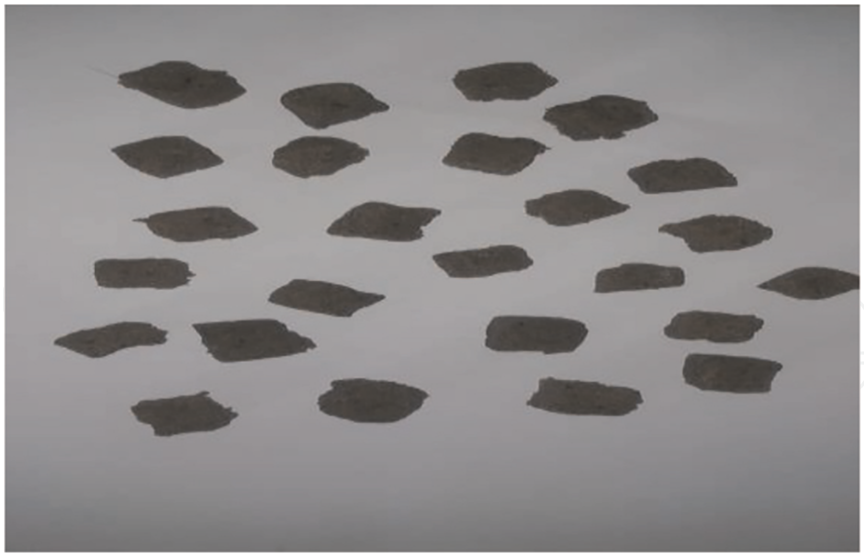

Figure 20.
Cube production from different batches.

in a state of statistical control. No significant assignable variation is detected. Slight differences observed in the weight of the product are due to inherent chance variations that are inevitable in any production process. Cubes produced from different batches as they are released from the cubing unit are shown (**Figure 20**).

1.5 Effects of processing on product quality

The results of proximate analysis of the cubed and un-cubed powder (**Table 11**) show a rapid decrease compared with 42.65% reported in Ref. [50]. The reduced moisture content could be the result of the drying process at 60°C for 24 hours, and this might improve the storability of the condiment. The crude fat content of the un-cubed sample was 12.13%, while that of cubed sample was 12.12%. These values are closely related to 10.65% reported in Ref. [51]. The results show that the values of crude protein for un-cubed African locust beans sample was 80.25% while that for cubed sample was 80.18%. The result of 37.32% obtained for the protein content of naturally fermented African locust beans is, however, in line with that reported in Ref. [50], while the increase in the fiber content of the cubed sample over the un-cubed sample could be traced to be an effect of the hydrophilic and lipophilic tendency of lecithin used as binding agent [52].

Nutrient	Un-cubed locust beans (%)	Cubed locust beans (%)
Moisture content	6.43	5.43
Crude fat	12.13	12.12
Crude protein	80.25	80.18
Crude fiber	0.48	0.86
Total Ash content	0.61	0.92
Carbohydrate content	0.12	0.50

Table 11.
Proximate composition of un-cubed and cubed fermented African locust beans.

1.6 Processing Losses

The process of transforming raw ingredients into food through any of these technologies usually leads to nutrient losses. These losses may arise due to sensitivity to heat, light, oxygen or pH of the solvent, or a combination of these. Food fortification, which is the addition of one or more essential nutrients to food, is often employed as one way of restoring such losses occurring during processing or correcting a demonstrated deficiency in the population. Vitamin A, iodine, and iron remain three of the most important micronutrients from a public health perspective, and wheat flour, sugar, vegetable oils, and salt are some of the commonest vehicles for carrying these nutrients in food products. We have studied in our laboratories, in particular, the effects of baking and frying on the vitamin A and iron contents of pan bread and doughnuts [53]. The results obtained showed slight variations in vitamin A and iron levels of treated and market flour samples (**Table 12**), vitamin A content of pan bread (**Table 13**), vitamin A content of fried doughnuts (**Table 14**), as well as iron levels of baked pan bread (**Table 15**) and fried doughnuts (**Table 16**), respectively.

From these results (**Tables 13–16**), the baking process at 175°C for 45 minutes using dough proofed for 60 minutes retained more vitamin A than deep-fat frying at 185^0 C for 5 minutes using dough proofed for 45 minutes, while process losses of iron were comparable [54]. Nevertheless, a 25–35% vitamin A loss was recorded during baking compared to a 33–40% vitamin A loss recorded after deep-fat frying.

Clearly, these results confirmed that iron is more stable under various processing conditions except in the presence of moisture. Similar baking and deep-fat frying studies also showed that during baking at 175°C for 45 minutes with dough proofed for 60 minutes, only a 6–10% loss of iron was recorded. The iron retention was better in dough proofed for 90 mins compared with deep-fat frying at 185°C for 5 mins where a 6–15% loss in doughnuts was obtained.

Flour type	Vitamin A content (2 g)	Iron levels (ppm)
Blank	6000 IU	58
Treated	35,000 IU	66
Market	27,500 IU	68

Table 12.
Vitamin A and iron levels of blank, treated, and market wheat flour samples.

Flour type/Proofing time (mins.)	Vitamin A level before baking (IU)	Vitamin A level after baking (IU)	% loss
Blank: 30	5000	3500	30
60	4000	3000	25
Treated: 30	27,500	18,000	35
60	33,000	24,000	27
Market: 30	24,000	16,000	33
60	28,000	22,000	21

Table 13.
Vitamin A content of pan bread before and after baking at 1750C for 45 minutes.

Flour type/Proofing time (mins.)	Vitamin A level before frying (IU)	Vitamin A level after frying (IU)	% loss
Blank: 45	5000	3000	40
90	3000	2000	33
Treated: 45	24,000	15,000	38
90	27,500	17,000	38
Market: 45	15,000	10,000	33
90	17,000	9000	47

Table 14.
Vitamin A content of fried doughnuts before and after deep frying at 1850C for 5 minutes.

Flour type/Proofing time (mins.)	Iron level before baking (ppm)	Iron level after baking (ppm)	% loss
Blank: 30	32	29	8
60	35	33	6
Treated: 30	54	49	9
60	56	52	7
Market: 30	53	47	11
60	66	61	7

Table 15.
Iron levels of baked pan bread before and after baking at 1750C for 45 minutes.

Flour type/Proofing time (mins.)	Iron level before frying (ppm)	Iron level after frying (ppm)	% loss
Blank: 45	50	47	6
90	41	34	8
Treated: 45	63	57	10
90	78	65	6
Market: 45	60	55	8
90	68	57	15

Table 16.
Iron levels of fried doughnuts before and after deep frying at 185°C for 5 minutes.

Similarly, marked differences are observed in the effects of different ingredients on vitamin A retention in pan bread from fortified flour samples (**Table 17**), as well as under different storage conditions (**Table 18**).

One of the benefits of dough proofing has been reported to be in helping to reduce the level of phytic acid in bread. This is because phytic acid is a known inhibitor of micronutrients present in cereals. Yeast fermentation has also been reported to significantly reduce the phytic acid concentration in bakery products [55], thus increasing the bioavailability of these micronutrients [56, 57]. This is why proofing of dough should be encouraged as a standard practice before baking, deep fat frying, or other

	Flour	Control	High yeast	Low yeast	High salt	Low salt
Treated	26,817	27,066	17,652	21,235	27,282	20,334
Market	10,640	15,207	14,260	15,646	15,950	12,070
Blank	1864	6286	4833	6523	6658	4644

Table 17.
Effect of ingredients on vitamin A retention in pan bread from flour samples (IU).

Day		Sunlight	Shelf	Refrigerator
1	A	1430	1452	1469
	B	27,653	27,830	27,819
	C	11,829	11,935	11,917
2	A	1409	1419	1421
	B	27,624	27,641	27,646
	C	11,812	11,817	11,823
3	A	1392	1408	1414
	B	27,588	27,628	27,637
	C	11,793	11,801	11,814
4	A	1376	1399	1405
	B	27,565	27,613	27,629
	C	11,777	11,794	11,805
5	A	1357	1386	1397
	B	27,526	27,572	27,614
	C	11,754	11,783	11,798

A—Bread from blank flour containing 1000 IU; B—Bread from treated flour containing 30,000 IU of vitamin A/1 kg; C—Bread from standard market sample (fortified).

Table 18.
Effect of storage on vitamin A retention in pan bread from flour sample (IU).

processing methods, as this helps to increase the bioavailability of the iron by reducing the level of phytic acid and its inhibitory effects in the product.

2. Conclusion

Significant advances in the upgrade of traditional processing technologies of roasting, frying, smoking, and fermentation have been recorded in the recent years. The design development and evaluation of a manually operated multi-heat source roaster, which shows significant promise from the evaluation of the proximate, mineral, and vitamin B6 compositions of roasted plantains using gas, electric, or charcoal as the heat sources, has been reported in this review. Consumer perception of the roasted plantain indicated that the product from charcoal roasting was the most acceptable to the panelists. From all indications, the multi-heat source plantain roaster is affordable and could be easily adopted for the purpose of upgrading the rural technology of plantain roasting and eliminating the associated drudgery and likely contamination of such products.

The application of frying technology to traditional deep-fat fried products like *chin-chin* has also been evaluated. Here, it is noted that conductive heat transfer is equal to the combination of convective heat transfer within the hot oil, with conductive heat transfer to the interior of the food and heat losses as a result of radiation. The results show that c*hin-chin* fried with corn oil gave the least fat uptake followed by soya oil. This is significant given the knowledge that high fat intake in the human system causes various noncommunicable diseases, especially of a cardiovascular nature [58]. The results also show that vitamin A retention is highest when electric heat is used, compared to other heat sources, with the machine capacity ranging from 5.60 to 8.60 kgh^{-1} depending on the heat source.

From the evaluation of the performance of the smoking kiln for the production of smoked fish and meat products, the efficiency of moisture loss per unit time showed that charcoal is the most efficient as a source of heat by conduction and convection within the smoking chamber as well as by radiation. From the design calculations, it is estimated that the heat capacity of the kiln exceeds the heat requirement for each of the smoked products. The smoking kiln is specifically designed to be relatively cheap, affordable, and easy to maintain for small- and medium-scale processors. The use of fiber glass as an insulator between the double-jacketed walls of the kiln helps to minimize heat losses, thereby increasing efficiency. Consumer perception of various smoked products also showed high acceptability to panelists.

The processing of fermented, dried, and cubed African locust beams has also been shown to be a very significant technology upgrade, with the resulting cubed product being more hygienic and storable, with high nutrient retention compared to the traditional powdered product.

It is concluded therefore that these various advances in the development of affordable, functional, and adaptable technologies offer significant opportunities for small- and medium-scale processors, especially in low- and middle-income countries where adaptability to various energy supply conditions is critical. With the ease of operation, maintenance, and durability, these equipment hold significant promise for use by food processors at small- and medium-scale levels, while with the assurance of high nutrient retention, the benefits of consuming fortified products processed by these traditional technologies will be realizable.

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