

Development of a Multifunctional Oven using Agricultural Waste as a Heat Source

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ABSTRACT: This study was conducted to design, manufacture, and evaluate the performance of a multifunctional oven that uses agricultural waste combustion as a heat source for drying, smoking agricultural products, and baking bread. The machine was developed and built to properly dry pepper, smoke fish, bake bread, and grill with locally accessible materials. The machine described comprises an agricultural waste combustion chamber designed specifically for burning agricultural waste material. This is accompanied by a drying chamber dedicated to the drying of biomaterials. The two chambers are connected by a heat transfer duct, which serves the purpose of transferring the heat generated during the combustion process. The utilization of agricultural waste material as a fuel source is particularly advantageous due to its widespread availability in many regions. This not only presents an opportunity to reduce environmental pollution but also provides a cost-effective and sustainable solution for farmers. By repurposing agricultural waste in this manner, the machine offers a practical and environmentally friendly approach to addressing the energy needs of agricultural operations. The fabrication process entails the meticulous design and construction of a combustion chamber specifically engineered to effectively burn agricultural waste. This combustion process is meticulously calibrated to generate sufficient heat to facilitate the drying of pepper, smoking of fish, and baking of bread. The performance of the dryer machine is rigorously evaluated, with a keen focus on its drying rate, drying capacity, and affordability. Through this comprehensive evaluation, recommendations for potential improvements are meticulously outlined, with a view towards enhancing the overall efficiency and effectiveness of the system. The obtained drying rate of 90.9% and drying capacity of 727 kg/day at a temperature of 150°C, along with a baking capacity for 480 kg of dough at 180°C for 20 minutes, demonstrate the promising potential of this new technology. The development of this equipment represents a significant advancement in ensuring food security and economic stability in a sustainable and cost-effective manner. Furthermore, it has the capability to address the challenges of nutritional loss and high energy consumption commonly associated with most drying technologies. This innovation holds great promise for enhancing food preservation processes and contributing to the overall efficiency and sustainability of food production.

Keywords: Agricultural, development, dough, fish, multifunctional, oven, pepper

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INTRODUCTION

Food security is a major concern, as it is predicted that the global population will double by 2050. This brings attention to the need to make food accessible, affordable, preserve the food quality and ensure sustainability in order to achieve food security. Ibrahim et al. (2023) define food security as ensuring that everyone, everywhere, has physical and financial access to enough nutritious food that satisfies their dietary requirements and nutritional needs for an active and healthy life. According to Tielens and Candel (2014), achieving food security requires more than just producing food;

waste must also be minimized by using the right food preservation and storage techniques, which make sure that the food is consumed outside of its place of origin and lasts for a longer amount of time. This is the point at which using the appropriate food preservation solutions is crucial. The drying method is one of the preservation techniques that could lead to food security. The use of novel drying technology that enables food security and economic stability in a sustainable and cost-effective manner that meets the expectations of consumers is important. Thus, the need for high-quality food

preservation has sped up and significantly led to the development of novel drying methods (Ibrahim et al., 2023). In both industrial and agricultural processes, thermal drying is a popular technique for removing moisture from agricultural products. Also, it has been identified as one of the most important technological processes for raising product quality (Murugan et al., 2021). According to Pirasteh et al. (2014), the energy requirement for drying can be supplied from various sources, namely, electricity, wood, bark forest residual (biomass), and solar. Open-sun, solar, and oven drying techniques are frequently used to dry agricultural products. In Nigeria, open-sun drying is the traditional technique for products. This process results in food losses, dust, stone, and insect contamination, and the loss of several minerals, including vitamin C. Produce is exposed to direct sunlight, rain, and dust during the uncontrolled process of open-sun drying. Open-sun drying produces unpredictable product quality; hence, food products dried using this method are not desired (Sagar and Kumar, 2010; Afolabi et al. (2015). Emelike and Akusu, (2020) asserts that sun drying causes food to lose colour, shrink, and provide an unpleasant final product. The solar drying technique has the advantages of simplicity and lower initial investments; nonetheless, it is a labour-intensive process that requires long drying times (Andritsos et al., 2003). New industrial drying technologies, including hot-air drying, are now employed in place of the conventional open sun drying approach to enhance the quality and value of dried products. According to Ononogbo et al. (2021), the use of hot air in controlled tray drying proves to be fruitful as it provides uniformity and hygiene for food drying processes, which becomes inevitable. Drying using electricity requires high energy usage, which accounts for approximately 15% of electricity consumption. It is, therefore, very crucial to identify the optimum design and use of the drying process. Oluseun and Adebukola, (2021) report that food preservation in developing countries with significant agricultural activities cannot be dependent on electricity, as they have poor electricity supply or a lack of rural electrification. Also, where available, the power supplied is epileptic, and most of the rural areas lack rural electrification. According to Gunathilake et al. (2018), oven drying technique uses heat to reduce the moisture in food to a bare minimum by evaporation. This drying process is used to dry plant materials at particular temperatures over a set amount of time. Oven drying is becoming more popular in the food processing industry due to lower manufacturing costs, resulting in more cheap products for customers. During the drying process, oven dryers produce greater temperatures, lower relative humidity, lower product moisture content, and less spoilage. Additionally, it is quicker, less time-consuming, and reasonably priced. Therefore, oven drying is a superior substitute for all the problems with natural drying and serves as one option for a solution to global energy

and food problems. Using biomass to power oven dryers is considered one of the most promising future energy sources. As there are several million metric tons of biomass, such as forestry harvesting residues, wood chips, sawdust, sugarcane bagasse, and agricultural residues from grain and fruit processing, are available (Nawshad and Michael 2013). A lot of research has been carried out on the development of biomass-powered oven dryers, and these include: Shittu and Umar (2020) developed a charcoal-fired fish dryer for small-scale processors. Anyanwu (2021a,b) developed a charcoal dryer with a manual blower and used it to dry fish and okra on two trays. Mehmet and Halil (2021) designed and carried out the implementation of a smart and automatic oven for food drying. Nwabudike et al. (2023) fabricated a mirror stainless steel oven drying machine as a technology for sustaining and preserving fish production. It is obvious that most of these dryers are designed for a particular agricultural product. Therefore, this study is on the development of a multifunctional oven using agricultural waste as a heat source, capable of drying different agricultural products, smoking fish, and baking bread.

MATERIALS AND METHODS

Machine description

Frame

This is a mounting support for the agricultural waste combustion chamber and the heating unit to make the machine and its part stand without the operator holding it. It is shown in (Figure 1 and Plate I).

Agricultural waste combustion chamber

The agricultural waste will be burned in this chamber as heat is transferred from the drying chamber through the heat transfer duct. It contains the ash tray, which is a receptacle for ash. It is a detachable tray that is intended to gather ash from burned agricultural waste used as the oven's heat source. Since adequate heat is produced, grilling also takes place inside the chamber (Figure 1 and Plate I).

Heat transfer duct

This component of the machine transports heat and smoke from the heating chamber's to the drying chamber. It is shown in (Figure 1 and Plate I).

Heating unit

A compartment for drying and smoking is included in the rectangular heating unit. It contains the rack tray, which is a detachable tray used to spread items out throughout

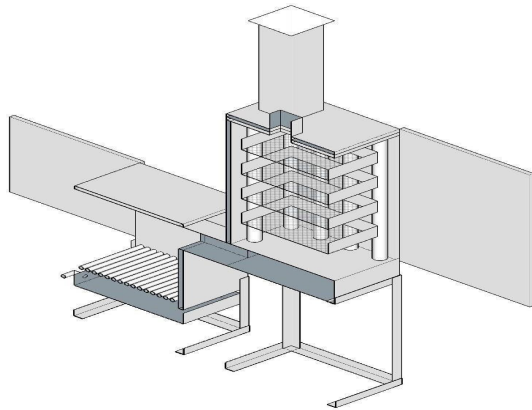


Figure 1. The exploded view of the machine.



Plate 1. The developed Multifunctional oven.

the drying, smoking, or baking processes so that heat is distributed equally across the biomaterial (Figure 1 and Plate 1).

Heating chamber

The heating chamber particularly generates an amount of heat with the temperature range required for the baking, smoking and drying. The source of heat is agricultural waste (corn cob, groundnut pod, rice husk).

Chimney

The chimney is attached to the machine for discharge of smoke. It is made with 16-gauge flat plate (Figure 1 and Plate 1).

Working mode of the machine

The biomaterials (fish, pepper, and dough) to be dried, smoked, or baked are loaded into the rack in an enclosed drying chamber. The biomaterial waste is lit in the combustion chamber, and the trapped heat is passed through an opening from the combustion chamber through the heat transfer duct, which carries the heat to the drying chamber. The burning waste supplies the heat, which dries the pepper, smokes the fish, and bakes the bread. But note that before placing the biomaterial for any function, it is necessary that the waste is lit in the combustion chamber and the bad smoke is allowed to go out to avoid a smoky smell on the material.

Design of the major parts of the equipment

Determination of size of oven

The size of the oven was determined as reported by Gana (2016), and is given as follows;

$$V = l \times b \times h \tag{1}$$

$$V = \frac{m}{\rho} \tag{2}$$

$$l \times b \times h = \frac{m}{\rho} \tag{3}$$

$$h = \frac{m}{\rho \times l \times b} \tag{4}$$

Where, V is the volume of oven (m³), L is the length of the oven (m), b is the breadth of the oven (m), h is the height of the oven (m), ρ is the density of the oven (kg/m³).

Determination of number of drying racks

The numbers of drying racks require was obtained as follows:

$$N_r = \frac{M_t}{M_r} \tag{5}$$

Where, N_r is number of racks, M_t is the total mass of biomaterials to be dried in (kg), M_r is the mass of biomaterials per rack in (kg)

Determination of the height of the biomaterial in each rack

The height of the biomaterial in each rack was determined as follows

$$h_r = \frac{M_r}{\rho \times l \times b} \tag{6}$$

Where h_r the height of the rack (m) is, M_r is the mass of biomaterials per rack in (kg), ρ, l, b have been defined earlier.

Determination of total height of dryer

The total of the dryer was determined by considering the height of the drying racks, the clearance between the racks and also the clearance at the bottom and top of the racks (Figure 2). It was calculated as follows:

$$h_t = N_r(h_r) + N_c(C) \tag{7}$$

Where h_t is the total height of the dryer (m), N_r is the number of the racks, h_r is the height of the racks (m), N_c is the number of the clearance below and above the racks, C is the height of the clearance (m).

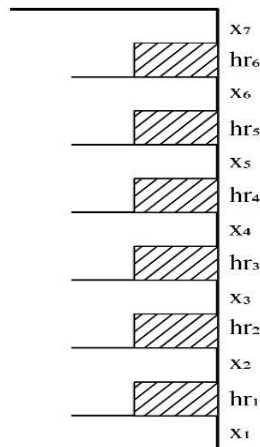


Figure 2: Spacing between racks.

Determination of amount moisture to be remove

The amount of moisture to be removed was determined as reported by Shittu and Umar (2020), and is given as follows:

$$M_{am} = \frac{M_c(M_{ci} - M_{cf})}{100 - M_{cf}} \tag{8}$$

Where M_{am} the amount moisture to be removed (%) is, M_c is the mass of material to be dried (kg), M_{ci} is the initial moisture content of the material to be dried (%), M_{cf} is the final moisture content of the material (%).

Determination of heat required to dry selected biomaterial

The amount of heat needed to dry each biomaterial was determined as reported by Shittu and Umar (2020), and is given as follows:

$$Q = M_c C_p \Delta t + I_v M_{am} \tag{9}$$

$$\Delta t = T_f - T_i \tag{10}$$

Where Q is quantity of heat (J), M_c is the mass of material to be dried (kg), C_p is the specific heat capacity of the material (J/kg °C), Δt is temperature difference (°C), T_i is ambient temperature of the oven, T_f is final dry temperature, I_v is the heat of vaporization (kJ/kg), M_{am} is the weight of moisture to be removed from the fish (kg)

Determination of heat loss through the walls of the dryer

Heat loss through the dryer's walls is anticipated despite its insulated walls (Figure 3), and the following assumptions were made;

- i. The heat transfer through the walls of dryer is steady and the surface temperature remains constant.
- ii. The thermal conductivity is constant.
- iii. The heat transfer is one dimensional since any significant temperature gradients will exist in the direction from indoor to outdoor.

Therefore, the heat loss is calculated reported by Gana and Gbabo (2017), and is given as follows:

$$Q_w = \frac{KA(T_f - T_i)}{L} \tag{11}$$

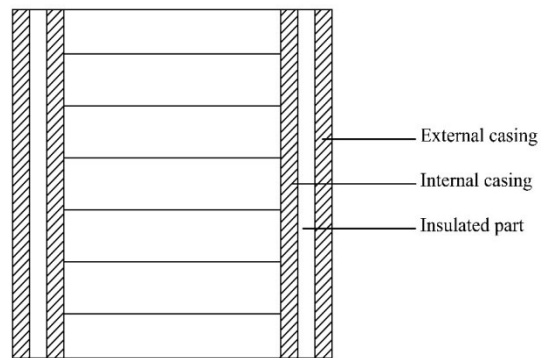


Figure 3: Internal and external casing with insulator in between.

Since the walls of the dryer consist of three walls of which two are mild steel and rock wool insulator. Therefore

$$Q_w = \frac{k_m A(T_f - T_i)}{L_m} + \frac{K_r A(T_f - T_i)}{L_r} + \frac{K_m A(T_f - T_i)}{L_m} \tag{12}$$

$$Q_w = 2 \left[\frac{K_m A(T_f - T_i)}{L_m} \right] + \frac{KA(T_f - T_i)}{L_r} \tag{13}$$

Where, Q_w is the quantity of heat that flow through the

wall of the dryer (J), K is the Thermal conductivity of the wall, K_m is the Thermal conductivity of the mild steel wall, K_r is the Thermal conductivity of the rock wool wall, A is the Cross sectional area of the dryer wall, T_i is the Internal temperature ($^{\circ}\text{C}$), T_o is the Outer temperature ($^{\circ}\text{C}$), L is the Thickness of the dryer wall (m), L_m is the Thickness of the mild steel plate (m), L_r is the Thickness of the rock wool insulator (m)

Determination of heat loss on the walls of the pipe

Calculations of the heat loss on pipe walls are done to determine the temperature differential between the heat generation point (the heating chamber) and the heat consumption point (the oven), as well as the resulting reduction in temperature and increase in heat generated. The heat loss on the walls of the pipe is calculated below Assume the length of the pipe should be 1m

$$Q_p = SK(T_f - T_i) \tag{14}$$

$$S = \frac{2\pi L}{0.785 \ln (a/b)} \tag{15}$$

Where, Q_p is the quantity of heat loss in pipe (J), S is the conduction shape factor (m), T_f is the inside temperature ($^{\circ}\text{C}$), T_o is the Outside temperature ($^{\circ}\text{C}$), L is the length of pipe (m), a is the total width of pipe (m), b is the internal width of pipe (m)

Determination of the quantity heat expected at the dryer

The amount of heat needed to achieve the desired 70°C was calculated as reported by Gana and Gbabo (2017), and is given as follows:

$$Q_T = Q + Q_w + Q_p \tag{16}$$

Where, Q_T is the total quantity of heat required (J), Q_w is the quantity of heat that flow through the wall (J), Q_p is the quantity of heat loss in pipe (J),

Determination of the quantity of agricultural waste required

The quantity of agricultural waste required to produce the necessary heat was determined as reported by Shittu and Umar (2020), and is given as:

$$Q_B = \frac{Q_T}{C} \tag{17}$$

Where, Q_B is the quantity of biomass required (kg), Q_T is the total quantity of heat required (kj), C is the calorific value of the agricultural waste (j/kg),

Testing of the machine

After the fabrication, the machine was tested for drying, smoking, and baking. This was done in order to determine the functionality of all parts of the machine and ensure that there was no leakage at the drying unit. The test was done in batches for all the products.

Experimental setup

Three different experiments were carried out using the equipment; these included the drying of pepper, baking of bread, and smoking of fish.

Drying of pepper

Thirty kilograms of pepper were purchased from a new market in Bida. The pepper was cleaned, then divided into 2 kg samples and dried in the oven at different temperatures. These drying temperatures were measured with a thermometer. The drying chamber's temperature was also measured using a thermometer that was installed inside it. The drying times for the material were independently noted. Samples of the dried pepper are shown in (Figure 4).



Figure 4: The drying process of pepper (a) is the pepper inside the dryer (b) is the dried pepper.

Baking

An agricultural waste was ignited within the oven's heating chamber to provide the required temperature for the test. The dough was taken from a dough mixer developed at the department and kneaded before being placed on a flat plate. After being kneaded, the dough was divided into 10kg, 15kg, and 20kg and placed inside a pan. When the oven's temperature matched the required test temperature after the heat generated from the heating chamber was channeled into the oven via the heat transfer duct, the pan was then put on the rack. The bread was then baked in the oven. The test was conducted at various temperatures, and samples of the baked bread are shown in (Figure 5).

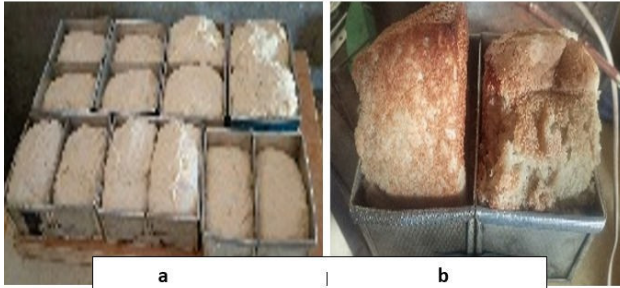


Figure 5: The baking process of bread (a) the kneaded dough (b) is the baked bread.

Smoking

Agricultural waste was placed inside the combustion chamber and ignited to generate the heat needed to heat up the oven. The heat generated was transferred through a heat transfer duct to the oven. The chimney was opened to allow for the outflow of bad smoke. After that, the internal temperature of the oven was allowed to match the test temperature. Bida was washed and bent to a circular shape; it was then placed on the racks inside the oven. The weight of the fish and the temperature of the oven were checked every 30 minutes, and samples of the smoked fish are shown in (Figure 6).



Figure 6: The smoking process of fish (a) is the fish inside the dryer (b) is the smoked fish.

Performance Testing of the Dryer

Drying of pepper

Drying rate

This is the rate at which moisture is removed from the biomaterial. It was determined as reported by Dhanushkodi et al. (2015).

$$D_r = \frac{M_i - M_f}{t} \quad (18)$$

Where, D_r is the drying rate (kg/hr), M_i is the initial mass (kg), M_f is the final mass (kg).

Drying capacity

The drying capacity is the amount of load or weight of bio material the oven can take in a particular time, in this case 8 hours in a day.

$$D_c = \frac{M_m}{T} \quad (19)$$

Where, D_c is the drying capacity (kg/day), M_m is the mass of bio material dried (kg), T is the time (hr)

Baking

Colour

This is the appearance of the bread under different temperatures at 20 minutes. This was done by visual observation.

Texture

This is the feel by hand of the baked bread.

Baking capacity

The baking capacity is the amount of load or weight of dough the oven can take in a particular time, in this case 8 hours in a day.

$$B_c = \frac{M_m}{T} \quad (20)$$

Where, B_c is the baking capacity (kg/day), M_m is the mass of bio material baked (kg), T is the time (hr)

Smoking

Moisture content

The moisture content of a bio material is the quantity of water contained in the material. It was determined as reported by Dhanushkodi et al. (2015).

$$M_f = \frac{W_1 - W_2}{W_1} \times 100 \quad (21)$$

Where, M_f is the moisture content of fish, W_1 is the initial weight (kg), W_2 is the final weight (kg), Moisture content (%)

RESULTS

After the fabrication of the oven, it underwent testing of the functions it was designed for, which are drying,

Table 1: Results of Drying of Pepper using the developed dryer.

Temperature (°C)	Initial mass (kg)	Final mass(kg)	Mass removed (kg)	Time (hr)	Drying rate (kg/hr)	Drying Capacity (kg/8hr/day)
50	30	12	18	1	30	240
75	30	12	18	0.75	40	320
100	30	12	18	0.58	51.7	414
125	30	12	18	0.42	71.4	572
150	30	12	18	0.33	90.9	727

Table 2: Results of Smoking Fish using the developed dryer.

S/N	Time (min)	Temperature(°C)	Fish weight (kg)
0	0	100	2.00
1	30	145	1.56
2	60	160	1.43
3	90	180	1.19
4	120	150	1.10
5	150	140	1.02
6	180	150	0.75

baking, and smoking. From (Table 1), the drying rate ranged from 30 kg/hr to 90.9 kg/hr. The highest drying rate of 90.0 kg/hr. was obtained from drying at a temperature of 150°C for 0.33 hr., while the least value of 30 kg/hr. was obtained from drying at a temperature of 50°C for 1 hr. The capacity ranged from 240 to 727 kg/hr./day. The highest value of capacity of 727 kg/8 hrs./day was obtained from drying at a temperature of 150°C for 0.33 hr., while the least value of 240 kg/8 hrs./day was obtained from drying at a temperature of 50°C for 1 hr. From (Table 2), the weight of the fish ranged from 0.75 kg to 2 kg. The highest weight of 2 kg was obtained from the combination of a time of 0 min and a temperature of 100°C, while the weight of 0.75 kg was obtained from drying for 180 min at a temperature of 180°C.

DISCUSSION

Drying of pepper

The drying rate increased as the temperature increased, indicating that higher temperatures facilitated faster water evaporation. At 50°C, the drying rate was only 0.5%, while at 150°C it was 1.5%. Overall, the data suggests that higher temperatures lead to faster and more efficient drying, but it is important to balance this against potential negative effects such as overheating or damage to the material being dried. This is in agreement with the findings of Jamil et al. (2018), as the temperature of drying fruit waste in a rotary hot-air dryer increase from 60°C to 80°C, vitamin C and drying time decrease rapidly. Also, Ndukwu (2009) reported that the higher the drying temperature, the higher the drying rate. The drying capacity is the quantity of agricultural material the oven can dry per day. As the temperature increased, the drying capacity also increased. This is because higher temperatures promote faster evaporation of moisture

from the material, thereby reducing the time taken. This agreed with the finding of Madan et al. (2014), where it was found that the drying rate was increased at higher temperatures, thereby reducing the drying time and hence the capacity.

Performance of the oven for baking

As the temperature increases, the color of the material becomes darker. This could be the result of a higher temperature beyond certain values that resulted in the burning and roasting of the bread. This agreed with Ibrahim et al. (2023), where it was observed that increasing the baking temperature and time resulted in a dark crust color and reduced the color saturation. The best texture is achieved at temperatures of 150°C for 10kg of dough and 180°C for 15kg and 20kg of dough. The baking of bread at a higher temperature, typically around 400-450°F (200-230°C), is often recommended because it helps create a crisp and well-risen crust while maintaining a soft interior.

Performance of oven for smoking

It can be observed that the weight of fish decreases over time, indicating that the fish are losing weight. The fish weighed 2 kg at the start of the experiment and 0.75 kg at the end of the experiment (after 180 minutes). The temperature also fluctuated over time, with the highest temperature (180 °C) recorded after 90 minutes. This agreed with Idah and Nwankwo (2013), who found that moisture content decreased with increasing temperature and drying time.

Conclusion

The development of a multipurpose oven that uses agricultural waste as a heat source has shown to be

modern technology, beneficial for preserving various agricultural products such as pepper, smoking fish, and baking bread. The equipment is energy-efficient and requires minimal maintenance. The tests using pepper, fish, and bread dough demonstrated that the equipment worked well. The development of this equipment represents a new technology capable of ensuring food security and economic stability in a sustainable and cost-effective way. It can also address the issues of nutrient loss and the high energy use of traditional drying methods.

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