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DEVELOPMENT AND EVALUATION OF AN INDIGENOUS MULTI-HEAT SOURCE CROP DRYER

Kolawole Peter Oladiran^{*1}, Olajide Ayodele Sadiku¹, Gift Chinonye Gbaruko²

¹*Department of Soil Resources Management, Faculty of Agriculture,
University of Ibadan, Nigeria*

²*Department of Crop and Horticultural Sciences, Faculty of Agriculture,
University of Ibadan, Nigeria*

Abstract: Post-harvest losses pose a major threat to food security, often resulting from improper handling and preservation of agricultural produce. Drying is a critical preservation technique that reduces moisture content to maintain product quality, extend shelf life, and enhance ease of transportation. Although sun-drying remains a cost-effective and widely accessible method for rural farmers, it frequently compromises product quality, motivating the development of improved drying technologies. This study presents the design and performance evaluation of an indigenous multi-heat-source crop dryer equipped with a continuous airflow system powered by heat energy. The dryer was tested using plantain and sweet potato, with cooking gas and kerosene as heat sources, and compared against traditional sun-drying. Data collected included moisture loss, drying time, drying temperature, and environmental parameters such as ambient temperature and relative humidity. Statistical analysis conducted using R software revealed no significant differences in moisture loss among treatments; however, the drying period varied significantly. The mean moisture loss ranged from 0.30 kg to 0.32 kg for plantain and from 0.31 kg to 0.32 kg for sweet potato, while the drying time ranged between 90 minutes and 720 minutes for bananas, and 90 minutes to 840 minutes for sweet potato. The dryer achieved higher drying rates and greater efficiency when using gas and kerosene compared to sun-drying. Sun-dried samples exhibited greater color variation due to prolonged exposure.

Overall, the multi-heat-source crop dryer effectively reduced drying time, maintained product quality, and utilized readily available fuel sources, offering a practical and sustainable solution for reducing post-harvest losses.

^{*}Corresponding Author email: koladiran085@stu.ui.edu.ng

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INTRODUCTION

Postharvest management practices are critical for maintaining the quality of agricultural products, minimizing losses, and ensuring cost-effectiveness [1], [2]. Fresh fruits and vegetables, which have a high moisture content (approximately 80%), are particularly perishable and prone to rapid deterioration if not handled properly [1], [3], [4]. Food processing plays a vital role in extending the shelf life of agricultural products and reducing waste, especially for highly perishable commodities. For instance, fruits such as mangoes, citrus, and pineapples are commonly processed into juices to enhance preservation [5], [7]. Preventing food waste is essential for achieving sustainable food security.

Drying is one of the oldest and most widely used methods of food preservation. It reduces moisture content, inhibits microbial growth, enhances shelf life, and facilitates transportation and handling [3], [4], [6]. Drying processes are energy-intensive, accounting for 10–25% of total energy consumption in the global food processing industry [8 - 11]. Modern drying techniques, however, are increasingly designed to optimize energy use while maintaining product quality. The quality of dried products depends on the physical and structural changes that occur during moisture removal, which influence handling characteristics and stability under various environmental conditions [3], [4], [12], [13]. These outcomes rely heavily on the use of efficient drying techniques.

Traditional methods such as open sun-drying, although cost-effective and widely used by rural farmers [14], often result in substandard product quality due to contamination, discoloration, microbial spoilage, and non-uniform drying [15], [16]. Consequently, modern drying technologies-including solar dryers, thermal energy systems, and controlled electric dryers-have been developed to significantly improve drying efficiency and product quality while reducing postharvest losses [6], [12].

Nigeria faces serious challenges related to food insecurity, with substantial quantities of food lost annually. These losses are linked to several factors, among which inadequate postharvest management and poor storage practices are major contributors to food deterioration and wastage [5], [7]. High costs of imported dryers, unstable electricity supply in rural areas, and limited technical expertise have been identified as key constraints to effective postharvest management [7], [17]. In response to these challenges, various types of dryers powered by solar energy have been developed and evaluated [6], [13], [18], with the aim of reducing postharvest losses and improving drying efficiency. Similarly, in this study, an indigenous dryer using kerosene and domestic gas (methane) as heat sources was developed from locally available materials.

The dryer is user-friendly, requires minimal technical expertise, and incorporates key design features such as a continuous-flow drying system, exhaust outlets, and isolated heating chambers to ensure uniform drying without direct contact between the heat sources and the products.

The primary objective of this study was to design, fabricate, and evaluate an indigenous multi-heat-source crop dryer that meets the needs of rural farmers by providing a practical, cost-effective, and sustainable solution for preserving perishable agricultural products.

Experimental location

The fabrication of the Indigenous multi-heat source crop dryer was done at the Faculty of Technology Welding Workshop, Faculty of Technology, University of Ibadan (UI), Ibadan, Nigeria while the evaluation was performed at the Department of Agronomy, Faculty of Agriculture, in the same University.

Description of the indigenous crop dryer

The dryer was made detachable into upper part (drying chamber) made of stainless-steel plate and lower part (heating chamber) made of galvanized steel plate. The total height was divided into 60 cm (up) and 40 cm (down). The length and breadth were 50 x 50 cm. The following are the component parts of the dryer.

Heating chamber: This is the lower part of the dryer where heat is supplied to the dryer to raise the temperature of the ambient air in the air manifold.

Air manifold: It is attached to the drying chamber and this is where the ambient air temperature is raised to the required drying temperature for the removal of moisture from the product in the drying chamber. It was equipped with pipes on both sides to facilitate inward movement of air.

Drying chamber: This is the upper part of the dryer made of stainless steel. It is where drying process takes place and equipped with two mesh trays on which produce for drying are arranged. The external part was padded with plywood to prevent loss of heat by convection. It also prevents direct exposure to external cooling by humidity and moisture.

Exhaust point (vent): These are the openings located on the top of the drying chamber to enhance the escape of humidified air from the chamber in order to prevent condensation and re-dampening of the product.

Principle of operation

The dryer operates on the principle of convective heat transfer, utilizing a controlled airflow system to facilitate moisture removal from agricultural produce. The air manifold at the base of drying chamber was equipped with pipes on both sides designed for the inward movement of ambient air. This configuration ensures that the heat source does not come into direct contact with the product, thereby maintaining product quality and preventing scorching.

The incoming air is heated by the selected heat source (cooking gas or kerosene), and the resulting hot air is directed into the drying chamber. The heated air passes over the produce, which is arranged on a mesh tray to allow free and uniform flow of air across the material surface, thereby enhancing moisture evaporation.

To prevent condensation within the drying chamber, an upper vent is incorporated to allow the continuous escape of humidified air. This design maintains efficient drying conditions by avoiding moisture buildup within the chamber.

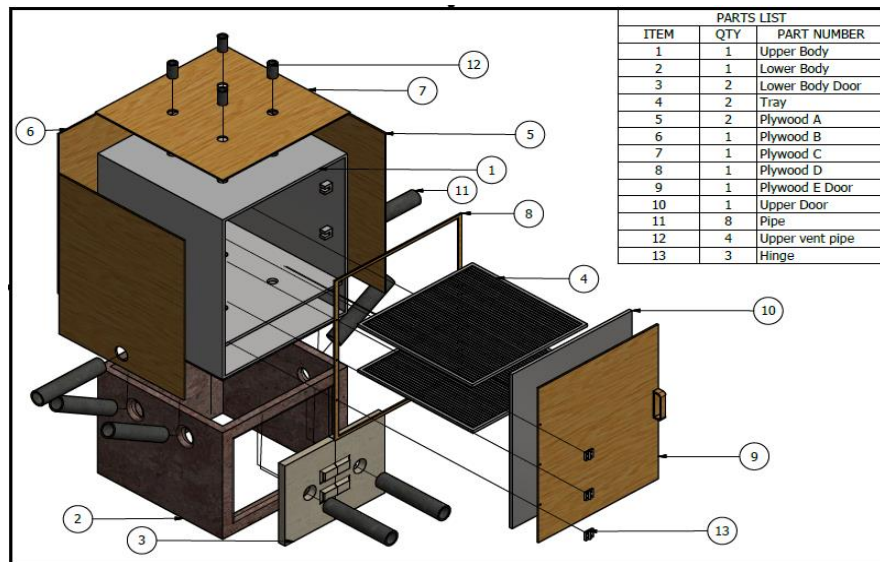


Figure 1. Isometric view of the multi-heat source crop dryer

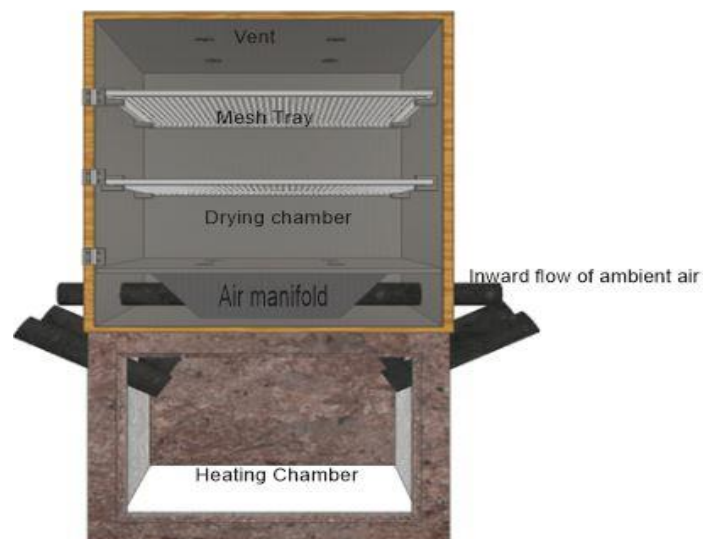


Figure 2. Annotated drawing of the indigenous multi-heat source crop dryer



Plate 1. Fabricated indigenous multi-heat-source crop dryer

Experimental design

The experimental design followed a Completely Randomized Design (CRD) in a 3×2 arrangement, representing three drying methods, two test crops and replicated three times. The treatments included sun drying, kerosene stove drying and gas cooker as heat sources using the dryer. The test crops; plantain and sweet potato, were selected for their importance in food security in Nigeria. However, these crops are highly susceptible to significant post-harvest losses due to their perishable nature and improper handling.

Sample preparation

The test crops were sliced into thin layers (0.5 - 1 cm) to enhance drying and arranged on a mesh tray inside the drying chamber. For each replicate, 0.5 kg of a test crop was prepared and dried in the dryer using a heat source. The experiment was carried out for each of the test crops using each of the heat sources. Drying temperature was monitored using a dry-bulb mercury thermometer and regulated to a preferred range (Table 3) by adjusting the flame intensity of the burner. A 3 kg gas cylinder and a kerosene stove were used as sources of heat energy. The heating chamber was monitored to prevent excessive heat buildup. The duration of drying using the dryer and sun-drying were recorded, along with the environmental conditions.

Data collection

- Ambient air temperature: This is the dry-bulb temperature of the ambient air which is considered as environmental temperature using a thermometer in degree Celsius (°C).
- Relative humidity: This is the amount of moisture present in the atmosphere using estimated value of weather forecast of the location was recorded in percentage (%).
- Drying temperature: This is the internal temperature of the dryer taken by place the thermometer through the exhaust point in degree Celsius (°C).
- Drying duration: This is the time taken to reach a constant weight in minutes (mins.).

- Moisture loss: This is the change in the weight of the material over time after drying to constant weight with the use of weighing balance in kilogram (kg).

$$\text{Moisture loss } (\Delta W) = W_i - W_f \quad \dots\dots\dots (1)$$

Where;
 ΔW is the change in weight,
 W_i is the initial weight while
 W_f is the final weight.

Statistical analysis

All data were analyzed using Analysis of Variance (ANOVA) in R software version 4.4.1, and mean separation using Duncan Multiple Range Test (DMRT) was performed to test for significant differences.

RESULTS AND DISCUSSION

Table 1. Table showing the interactions between the drying methods and the test crops

Source of variation	Plantain		Sweet potato	
	Moisture loss	Time taken	Moisture loss	Time taken
df	2	2	2	2
f. cal	0.1982	7450.87	1.05	23708.4
Prob >f	0.8254	< 0.0001***	0.4064	<0.0001***

Prob >f: 0.0001*** (highly significant)

Table 1 showed analysis of variance of result gotten from the drying process. There is no significant difference in term of moisture loss but a high significant difference was observed in the time taken. The drying of both plantain and sweet-potato with the dryer using different heat sources (cooking gas and kerosine) produced a well dried material without damage, contamination, burnt surface and odour within a period less than 2 hours for the whole replication. The direct inflow of air into the air manifold and the raising of the temperature aids the quick removal of the moisture. With the provision of exhaust point on the top of the dryer, the humified air were forced out of the drying chamber to maintain a continuous air flow during the process. Similar to the result of [18], [19], using solar energy for the multipurpose dryer, it takes 2 days or more for the test crops to be fully dried. In their result a fall in temperature was observed in the night which led to the reabsorption of moisture by the product. Hegde et al. (2015) reported that, the maximum ambient air and outlet air temperatures of a solar dryer for bananas were 34 °C and 45 °C, respectively. These temperature variations were attributed to fluctuations in solar energy throughout the day and the inability to control environmental factors such as air velocity and relative humidity which influence effectiveness of solar energy [20]. This limitation can adversely affect the drying process, particularly during prolonged periods of rainfall or cloudy weather.

Unlike sun drying, with the estimate of 4 hours per day, when the sun is at high intensity, to achieve a perfect weight of the dried product, it took 3 days for plantain and 4 days for sweet-potato to be fully dried. This is expected as it is impossible predict the relative humidity, the intensity and duration of the sun shine [8], [18], [20]. Though, it is a cheap source of energy but exposure to varying moisture condition, discoloration and contamination by dust reduces the quality and general acceptability of the product [16]. For a perfect drying process, it is important to maintain constant rate of drying within a short period of time to enhance productivity and quality.

Table 2. Showing the drying efficiency of the indigenous crop dryer using different heat sources compared with sun drying

Treatment	Moisture loss (kg)		Time taken (min)	
	Plantain	Sweet potato	Plantain	Sweet potato
Sun-drying	0.3a	0.32a	720a	840a
Kerosene	0.31a	0.32a	107.3b	115b
Gas	0.31a	0.31a	94.3b	105b

Note: Means with the same letter are not significantly different

Table 2 showed the drying efficiency of the Indigenous multi-heat dryer with different drying methods. Similar to the analysis of variance, moisture loss is uniform for all the drying methods while the time to achieve a perfect weight of the product showed a significant difference for both plantain and sweet potato. This showed that, under natural condition using sun drying, the rate of moisture removal from the product is very slow and varied between the test crops [10], [20]. The structure and textural class of plantain and sweet potato differs from one another which determines the rate of water loss. Using the dryer with a regulated and ideal temperature range of 65-70 and 70-80 (Table 3) for plantain and sweet potato respectively, the drying process falls between 2 hours with moisture losses of similar values. This indicated that, with a controlled and regulated temperature, both test crops can be fully dried within a short period of time. According to table iii, the environmental factors like ambient air temperature and humidity have less impact on the drying process using the dryer whereas in sun drying, the environmental factors determine the rate of drying and can prolong the drying period [20]. As seen in plates 2 and 3, the colour of the sun-dried product appeared dusty and whitish as a result of long exposure and reabsorption of moisture. Also, black patches were observed resulting from non-uniform drying per time.



Plate 2. Dried Plantain samples



Plate 3. Dried Sweet potato samples

Table 3. Drying and environmental condition during the drying process for plantain

Parameters	Kerosene			Gas			Sun-drying		
Replication	I	II	III	I	II	III	I	II	III
Ambient. air temp. (°C)	29	30	37	29	34	33	29-36	29-36	29-36
Rel. hum. (%)	25	20	18	32	16	16	15-20	15-20	15-20
Drying temp. (°C)	65-70	65-70	65-70	70-80	70-80	70-80			
Time (min.)	120	100	102	100	90	90	720	720	720
Initial weight (kg)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Final weight (kg)	0.197	0.183	0.204	0.185	0.194	0.200	0.195	0.195	0.201

Table 4. Drying and environmental condition during the drying process for sweet potato

Parameters	Kerosene			Gas			Sun-Drying		
Replication	I	II	III	I	II	III	I	II	III
Ambient air temp. (°C)	29	34	33	34	36	32	29-36	29-36	29-36
Rel. hum. (%)	32	16	16	15	14	18	15-20	15-20	15-20
Drying temp. (°C)	70-80	70-80	70-80	70-80	70-80	70-80			
Time (min.)	100	90	90	115	115	120	840	840	840
Initial weight (kg)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Final weight (kg)	0.185	0.194	0.20	0.190	0.192	0.180	0.177	0.178	0.192

Table 3 and 4 showed the parameters measured for different drying methods. Ambient temperature and relative humidity for sun-drying were estimate in accordance to the time when the sun is out with high intensity. This limits the time of drying to approximately 4 hours per day to prevent drop in temperature and increase in the humidity. Solar energy (sun-drying) is difficult to quantify and its temperature cannot be controlled to achieve the desired drying conditions [18], [20]. As a result, the drying process takes considerably longer compared to other methods under consideration.

Using the dryer, the drying temperature was checked and regulated with thermometer to 65-70 and 70-80 for plantain and sweet potato respectively [3] to avoid cracking and loss in quality. This helped to maintained continuous drying process within the time. It was observed that a slight changes in the relative humidity and ambient temperature caused a small difference in the time taken. Although the variation was not significant but it revealed that the environmental condition can have impact both positively and negatively as seen in the result of [18] and [19].

Adverse weather condition can be detrimental over a long period of time as it possible to cause increases in the time taken require to raise the temperature of the ambient air to drying temperature.

CONCLUSIONS

The development and testing of the indigenous multi-heat crop dryer have shown that agricultural produce can be efficiently dried within a short period using various heat sources.

While sun drying is cost-effective, it is limited by unpredictable weather conditions, making it difficult to ensure consistent drying and exposing the products to potential contamination from insects and dust.

The use of different heat sources in the indigenous multipurpose dryer has demonstrated its efficiency and versatility, enabling effective drying with locally available fuels such as cooking gas, kerosene, and charcoal. This affordability makes it particularly accessible for rural farmers, especially in areas where power supply is unreliable or absent. By employing local heat sources, the dryer can significantly reduce post-harvest losses of perishable produce. Additionally, gas is more environmentally friendly, generating minimal fumes, and is well-suited for larger-scale operations. Gas burners, with their wide flame circumference and high-pressure output, promote efficient heat transfer, making them ideal for commercial use.

Moreover, the dryer has the potential for future upgrades, including the integration of electric heating coils within the air manifold and the attachment of fans to enhance airflow during the drying process. It is recommended that future research focus on the shelf life and quality of dried products over time. Additionally, further exploration into the potential use of dried plantain and sweet potato flour in the production of cakes, snacks, and pastries would be valuable.

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RAZVOJ I EVALUACIJA DOMAĆE SUŠARE POLJOPRIVREDNIH KULTURA SA VIŠE IZVORA TOPLOTE

Kolawole Peter Oladiran¹, Olajide Ayodele Sadiku¹, Gift Chinonye Gbaruko²

¹Department of Soil Resources Management, Faculty of Agriculture,
University of Ibadan, Nigeria

²Department of Crop and Horticultural Sciences, Faculty of Agriculture,
University of Ibadan, Nigeria

Sažetak: Gubici posle žetve predstavljaju značajnu pretnju za bezbednost hrane, a često nastaju kao posledica nepravilnog rukovanja i skladištenja poljoprivrednih proizvoda.

Sušenje je ključna tehnika konzervacije koja smanjuje sadržaj vlage radi očuvanja kvaliteta proizvoda, produženja roka trajanja i lakšeg transporta. Iako je sušenje na suncu ekonomično i dostupno seoskim proizvođačima, ono često narušava kvalitet proizvoda, što podstiče razvoj poboljšanih novih tehnologija sušenja.

Ova studija predstavlja prikaz dizajna i evaluaciju domaće konstrukcije sušare za određene poljoprivredne kulture, sa upotrebom više izvora toplote, opremljene sistemom kontinuiranog strujanja vazduha koji koristi toplotnu energiju.

Sušara je testirana na uzorku banana i batata (slatki krompir), pri čemu su korišćeni gas i kerozin kao izvori toplote, a rezultati su upoređeni sa tradicionalnim sušenjem na suncu.

Prikupljeni podaci obuhvatali su gubitak vlage, trajanje sušenja, temperaturu sušenja i uslove okoline kao što su ambijentalna temperatura i relativna vlažnost vazduha.

Analiza izvršena pomoću statističkog programa pokazala je da nije bilo značajnih razlika u gubitku vlage između tretmana, iako je trajanje sušenja znatno variralo. Prosečan gubitak vlage iznosio je od 0,30 kg do 0,32 kg za banane i od 0,31 kg do 0,32 kg za batat (slatki krompir), dok se vreme sušenja kretalo u rasponu od 90 do 720 minuta za banane i od 90 do 840 minuta za batat (slatki krompir). Sušara je ostvarila veću brzinu sušenja i bolju efikasnost pri korišćenju gasa i kerozina u poređenju sa sušenjem na suncu. Uzorci sušeni na suncu pokazali su veće varijacije u boji zbog dužeg izlaganja.

Sveukupno, sušara sa više izvora toplote uspešno je smanjila potrebno vreme sušenja (u odnosu na sušenje na suncu), očuvan je kvalitet proizvoda i upotrebljeni su lako dostupni izvori energenata, nudeći praktično i održivo rešenje za smanjenje gubitaka posle ubiranja prikazanih poljoprivrednih kultura.

Ključne reči: Posle žetve, sušenje, sušara sa više izvora toplote, očuvanje

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