

Development and Performance Evaluation of a Mini Multipurpose Flash Dryer^A

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Abstract: Drying, as one of the oldest forms of preserving agricultural products, has evolved over the years with the development of improvised drying systems such as the flash dryer for processed agricultural products. A mini flash dryer was locally fabricated and designed and fabricated considering domestically available power sources of charcoal and cooking gas. It was evaluated using basic staple foods (cassava, cornstarch, and beans) mashes obtained from Bodija market, processed, milled, and weighed in 1 kg samples. A Data logger (ECB-DU4AWC, China) was used to measure the temperature and relative humidity of ambient air and exhaust air leaving the heat exchanger while a CO₂ monitor (2CO9, China) was used to check for safety of air. Key variables were moisture content, drying time, temperature, and relative humidity while Performance indicators such as the Final moisture content (FMC), drying efficiency, and efficiency of the heat exchanger. The average capacities of the flash dryer for cassava mash, cornstarch, and bean mash were 37, 40, and 25.2 kg h⁻¹, respectively. The average efficiencies of the flash dryer on cassava mash, cornstarch and bean mash were 81, 69 and 59 %, respectively. The cost of production of the machine was estimated to be N304,050. The developed mini multipurpose flash dryer performed well with a reasonable level of efficiency on cassava mash and corn mash. However, the machine performed well by reducing the drudgery associated with their drying operation.

Keywords: Locally fabricated, drying efficiency, corn, cassava, beans

^A The study does not require approval from an ethics committee. The article has been prepared according to research and publication ethics.

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Introduction

Drying is presumably the oldest techniques of preserving agricultural produce which can be sold for higher values during off-season, heat is used reduce moisture content thereby inhibiting microbial activities that can lead to food degradation (Champathi et al., 2018; Naseer et al., 2013). Milled agricultural products such as fruits, grains, tubers also possess a significant moisture content that must be reduced to prevent losses. Drying has over the years evolved from the conventional open drying to the development of dryers such as flash dryers, solar dryers, cabinet dryer, tray dryers, freeze dryers, vacuum dryers, drum dryers, tunnel dryer, belt conveyor dryer, fluidized bed dryers and spray dryers (Gbolagade, 2024). Milled products such as maize flour, yam flour, cassava flour, bean flour etc. are mostly sun dried to prevent moulds and this requires periodic repetition. The process is also dependent on climatic condition and is often associated with losses as well as contamination of dust, insects and dirt. This has necessitated the need for flash dryers.

The flash dryer unlike other dryers is used for heat-sensitive, granulated materials such as corn flour, cassava flour, bean flour, yam flour, cocoyam flour, cocoa, etc. whose value may be affected by browning (Avi and Irene, 2006; Palegrina and Crapiste, 2001). Recent developments indicate an increased activity in designing and building with studies encapsulating drying characteristics such as moisture content, drying air temperature, air velocity, drying rate and drying time to evaluate the effectiveness of various drying systems (Valarmathi et al., 2017; Kuye et al., 2010).

This research dwells on the local production of affordable, portable mini multipurpose flash dryers that can be powered by readily available resources (either charcoal and gas) for common granular food materials such as bean, corn, and cassava flour. The study would also evaluate the effects of drying conditions on the performance of the dryer as well as the proximate composition of the dried produce.

The study's innovatory aspect focuses on the development of a mini multipurpose flash dryer using two readily available communal source of power. The fact that it can also be used for a wide range of granular materials implies it is highly versatile. This study is expected to provide valuable information on efficacy, applicability, product quality and versatility of the mini flash dryer with a view to improve product value and subsequently improve the standard of living of farmers and food processors in rural communities.

Materials and Methods

Materials

Conceptual isometric models of the mini multipurpose flash dryer were drawn depicting major components. Figures 1 and 2 show the isometric view and drawing of the mini-multipurpose flash dryer respectively, while Figure 3 displays fabricated mini multipurpose flash dryer.

Design Consideration

The physical characteristics of various food products subjected to drying were taken into consideration for an appropriate and practicable design. The machine was ergonomically designed to enhance ease of operation and fabricated using locally available materials. Durability, rigidity, wear resistant, and vibration stability were among the feature design considerations for the machine.

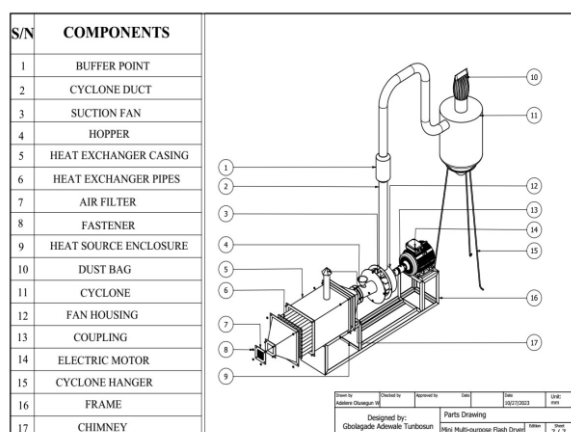


Figure 1. Isometric drawing of the mini multipurpose flash dryer

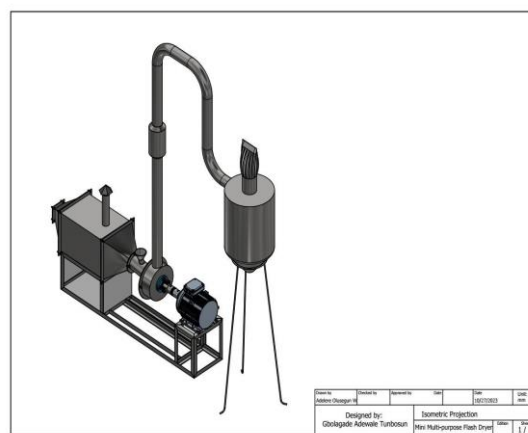


Figure 2. Isometric view of the mini multipurpose flash dryer



Figure 3. The complete mini multipurpose flash dryer

Machine Capacity

The loading capacity of the flash dryer was 60 kg h^{-1} . The machine was designed to regulate material intake over time, to avoid clogging within the drying duct. One kilogram (1 kg) of food mash will be fed through the hopper part positioned on the transition pipe linking heat exchanger and suction blower. The materials sucked in by centrifugal fan and conveyed through the dryer duct will be collected at the cyclone discharge chute.

Performance Evaluation

Cassava, corn and bean were obtained from Bodija market in Ibadan. They were processed by washing and peeling before grinding into mash using a 100 kg hr^{-1} stainless steel plate mill. The mashes were measured and separated into 1 kg samples. No-load testing was carried out by running the flash dryer for 15 minutes. A data logger (ECB-DU4AWC, China.) was used to measure the temperature and relative humidity of ambient air and exhaust air leaving the heat exchanger while a CO_2 monitor (2CO9, China) was used to check for safety of air. Gas and Charcoal were separately used to power the burner of the flash dryer. The dryer and dried matter were evaluated on the following:

Moisture Content Determination

The moisture content of the dried products was determined using an oven drying method according to ASABE standard (2008). The moisture content of the samples was calculated according to Equation (1) (Jonathan et al., 2017).

$$MC_{wb} = \frac{M_{wp} - M_{dp}}{M_{wp}} \times 100\% \quad (1)$$

where MC_{wb} is the moisture content of material in wet basis (%), M_{wp} is mass of sample before oven drying (kg), M_{dp} is mass of sample after oven drying (kg).

Heat Energy Supplied by the Fuel

The heat energy supplied by the fuel source was calculated using Equation (2) (Jonathan et al., 2017).

$$Q_1 = F \times C \quad (2)$$

where Q_1 is the heat energy supplied by the fuel (kJ), F is the amount of fuel consumed (kg), and c is the calorific value of the fuel source (gas and charcoal) (kJ kg⁻¹).

Energy

Energy received by ambient air (Q_2) is given in Equation (3) (Jonathan et al., 2017)

$$Q_2 = \rho \times V \times C_p \times T \times t \quad (3)$$

where ρ is the density of air (kg m⁻³), V is the volumetric flow rate of air (m³ s⁻¹), C_p is the specific heat capacity of air at constant pressure (J kg⁻¹ °C⁻¹), T the is temperature elevation by ambient air (K), and t is the drying duration (s).

Efficiency of Heat Exchanger Based on Each Source of Fuel

Efficiency of heat exchanger based on each source of fuel is given in Equation (4) while the energy used in removing moisture was calculated according to Equation (5).

$$\varepsilon = \frac{Q_2}{Q_1} \times 100\% \quad (4)$$

$$Q_3 = M \times L \quad (5)$$

where ε is the efficiency of the heat exchanger (%), Q_3 is the energy used in removing moisture (J), M is the mass of moisture removed (kg), and L is the latent heat of vaporizing at ion (J kg⁻¹).

Flash Dryer Efficiency

Flash dryer efficiency (Z) on each sample used for evaluation was calculated according to Equation (6).

$$Z = \frac{Q_3}{Q_1} \times 100\% \quad (6)$$

Statistical Analysis

The experimental data were analyzed using Analysis of Variance (ANOVA) and Linear Regression Analysis to determine whether there were significant differences in the variable measured across drying processes of cassava

mash and cornstarch. The ANOVA helped in comparing means for the drying efficiency, drying temperature, initial and final moisture contents etc. Significance was tested at a 95 % confidence level ($p < 0.05$). Post-hoc comparisons between treatment means were conducted using Duncan Multiple Range Test. All statistical analyses were performed in R version 4.3.1.

Results

A mini multipurpose flash dryer was designed and fabricated in this study using locally available materials. Figure 4, Figure 5 and Figure 6 portray the pictures of cassava, corn and beans mash before and after drying respectively.



Figure 4. Cassava mash before (left) and after (right) drying



Figure 5. Corn mash before (left) and after (right) drying



Figure 6. Bean mash before (left) and after (right) drying

Numerical experimental values obtained are presented in Tables 1 and 2.

Table 1. Standard deviations of the combined results obtained during performance evaluations

Sample Source of Fuel	Cassava Mash		Cornstarch Mash		Bean Mash	
	Charcoal	Gas	Charcoal	Gas	Charcoal	Gas
Initial moisture content (%)	0.0271	0.3633	0.1960	0.3708	0.0894	0.0894
Final moisture content (%)	1.8753	0.6201	0.8965	0.7878	0.2087	0.1757
Mass of sample after drying (kg)	0.0551	0.0117	0.0120	0.0248	0.0098	0.0089
Efficiency of flash dryer (%)	6.0024	2.0961	3.3337	2.9155	2.0512	1.6323
Ambient air temperature (inlet temp) of heat exchanger (°C)	0.5810	0.6112	0.5621	0.7068	0.5492	1.2023
Relative humidity of ambient air (inlet RH) of heat exchanger (%)	3.7550	0.9541	3.8593	0.9452	4.1788	1.8011
Air temperature (outlet temp) of heat exchanger into drying duct (°C)	0.8944	0.5083	0.8350	0.7246	0.5222	0.5177
Relative humidity of ambient air (outlet RH) of heat exchanger into drying duct (%)	1.2624	0.7030	1.0269	0.6601	0.8941	1.3732

Table 2. Analysis of variance for the samples and variable measures

Sample	Source of Fuel	Initial Moisture Content (%)	Final Moisture Content (%)	Mass of Sample Before Drying (kg)	Drying Time (S)	Efficiency Flash Dryer (%)	Ambient Air Temperature (°C)	Relative Humidity (%)	Outlet Temperature of Heat Exchanger Into Duct (°C)	Outlet Relative Humidity of Heat Exchanger (%)
Bean Mash	Charcoal	20.40± 0.0894a	14.52± 0.2087a	0.71± 0.0098a	3.00a	59.93± 2.0512a	28.92± 0.5492a	68.64± 4.1788a	67.54± 0.5222a	22.71± 0.8941a
	Gas	20.20± 0.0894a	13.94± 0.1757a	0.69± 0.0089a	3.00a	56.46± 1.6323a	29.37± 1.2023a	73.50± 1.8011b	67.60± 0.5177a	21.22±1.3732a
Cassava Mash	Charcoal	49.77 ± 0.0271a	32.35± 1.8753a	0.66± 0.0551a	3.00a	56.63 ± 6.0024a	28.68± 0.5810a	72.00± 3.755	68.50± 0.8944a	22.82 ± 1.2624a
	Gas	49.50± 0.3633a	27.23± 0.6201b	0.55± 0.0117b	3.12a	81.62± 2.0961a	24.78± 0.6112a	72.94± 0.9541a	68.94± 0.5083a	22.29 ± 0.7030a
Corn Starch	Charcoal	48.36± 0.1960a	32.32± 0.8965a	0.66± 0.012a	3.00a	69.08± 3.3337a	28.70± 0.5621a	71.94± 3.8593a	67.99± 0.8350a	22.60± 1.0269a
	Gas	48.17± 0.3708a	32.68± 0.7878a	0.67± 0.0248a	3.00a	58.64± 2.9155b	29.87± 0.7068a	72.91± 0.9452a	68.82± 0.7246a	22.12± 0.6601a

Relationship Between the Efficiency of the Flash dryer and Final Moisture Content (FMC)

The flash dryer efficiency and Final Moisture Content (FMC) of materials are typically inversely correlated: lower FMC is possible with higher drying efficiency, but reaching very low moisture levels frequently results in worse overall thermal efficiency, however drying biological materials exhibits anomalistic relationships such as those presented in Figures 7-12 due to their hygroscopic nature (Bello et al., 2020; Adegbite et al., 2023).

Figure 7 shows the correlation between the FMC of cassava mash and the efficiency of flash dryer using charcoal as a source of fuel. It was observed that cassava mash exhibited the highest rate of machine efficiency, which was 64.34 % recorded at FMC of 30.85 % and 30.87 %. It showed that the efficiency of flash dryer at 53.60 % was constant between 31.00 % and 33.80 %, while the flash dryer's efficiency at 50.28 % was recorded at FMC of 35.32 %. It shows a slightly average correlation with a R^2 of 0.6402.

Figure 8 shows the relationship between the FMC of cornstarch and the efficiency of flash dryer using charcoal as a source of fuel. It was observed that cornstarch exhibited the highest rate of machine efficiency which was 75.00 % at 30.83 % FMC. Generally, FMC was inversely proportional to the flash dryer efficiency briefly stable at 68.40% maintaining constancy between 32.3 - 32.5 % moisture content before reaching a terminal efficiency of 64.30 % at 33.5 % FMC. It shows a strong relationship supported by R^2 of 0.9962.

The associativity of the FMC and the efficiency of the flash dryer for beans mash using charcoal is portrayed in Figure 9. A constant maximum dryer efficiency of 62.5% was recorded for FMC of 14.2 and 14.35 % for bean mash. A steep decline in the drying efficiency was observed for FMC 14.35-14.6 % followed by a constant efficiency of 58.5 % for FMC of 14.73 - 14.78 %. It shows a strong association evidenced by R^2 of 0.9889.

Figure 10 depicts the association between the FMC of cassava mash and the efficiency of flash dryer using gas as a source of fuel. The flash dryer efficiency peaked at 85.93 % at FMC of 26.25 %. Conversely, the efficiency of flash dryer remained constant at 85.93 % as the FMC of cassava mash increased to 27.20 %. However, at the FMC of 27.33 % the efficiency of flash dryer decreased to 81.90%. This showed that the FMC is directly proportional to the flash dryer efficiency. At FMC of 27.33 % the efficiency of flash dryer dropped again to 80.00 % at 27.7 % FMC which later maintained its constant value of flash dryer efficiency till 28.23 % FMC. It shows a strong association shown by a R^2 of 0.9218.

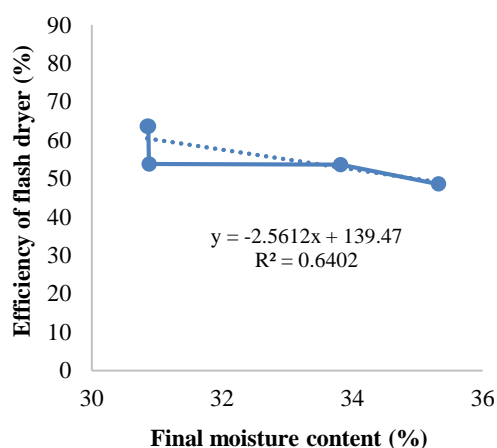


Figure 4. Effect of FMC on the efficiency of flash dryer (charcoal) for cassava mash

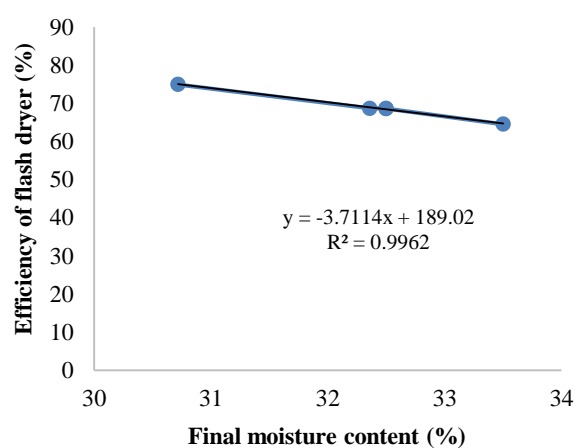


Figure 5. Effect of FMC on the efficiency of flash dryer (charcoal) for cornstarch

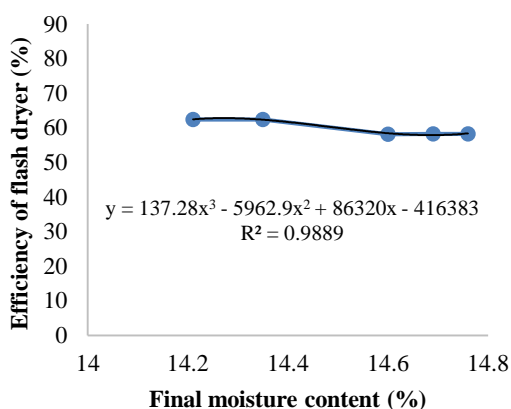


Figure 6. Effect of FMC on the efficiency of flash dryer (charcoal) for bean mash

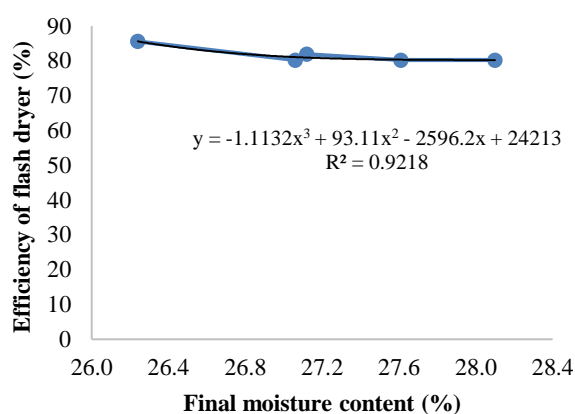


Figure 7. Effect of FMC on the efficiency of flash dryer (gas) for cornstarch

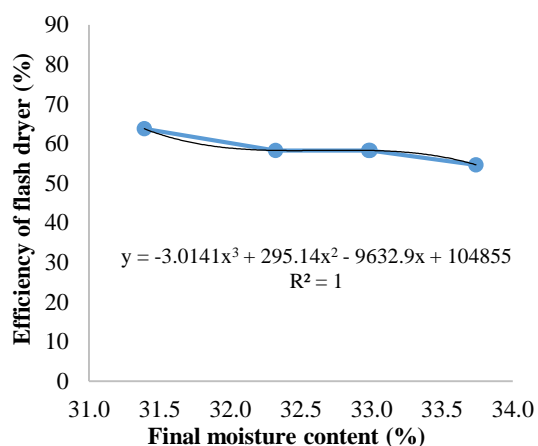


Figure 8. Effect of FMC on the efficiency of flash dryer (gas) for cassava mash

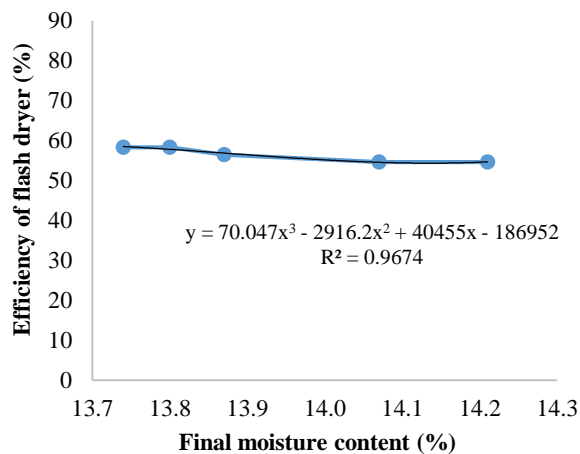


Figure 9. Effect of FMC on the efficiency of flash dryer (gas) for bean mash

The relationship between the efficiency of the flash dryer when powered by cooking gas and the FMC of cornstarch is displayed in Figure 11. The efficiency of flash drying peaked at 63.80 % at FMC of 31.48 %. An average efficiency of 58.00 % was recorded at FMC 32.41 - 33.00 %. Subsequently followed by a reduced efficiency of flash dryer of 54.38 % recorded at FMC of 33.75 %. This is represented by a perfect value coefficient of determinant R^2 value of 1.

A strong correlation between the efficiency of gas-powered flash dryer and FMC of bean mash evidenced by R^2 of 0.9674 is presented in Figure 12. A constant maximum efficiency of 58.30% was observed at FMC ranging 13.75 - 13.8 %. Reduced efficiencies of 56.49 % and 54.5 % were observed at 13.87 % FMC and 14.23 - 14.83 % FMC respectively.

Relationship Between Drying Air Temperature and Final Moisture Content (FMC)

A higher drying air temperature increases the air's ability to hold moisture, which improves moisture removal and typically results in a lower FMC and faster drying rates. Higher temperatures shorten drying times, but excessive heat might degrade quality by browning or causing thermal deformation (Potosi-Calvache et al., 2017).

Figure 13 depicts the correlation between the FMC of cassava mash and the temperature of the drying air when charcoal was used as a source of fuel represented by R^2 of 0.7115. It was observed that the air temperature was relatively constant around 69 °C for FMC between 30.82 – 35.35 %.

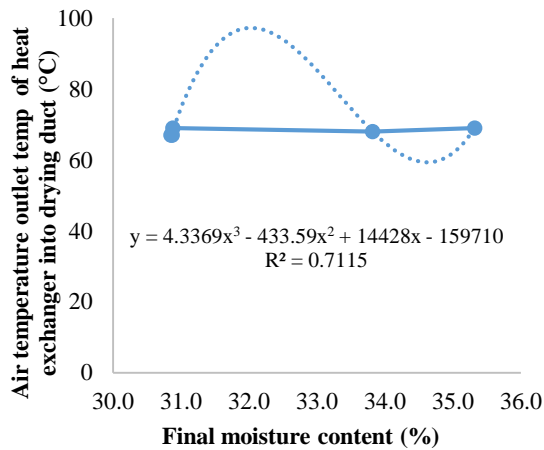


Figure 10. Effect of FMC on air temperature of heat exchanger (charcoal) for cassava mash

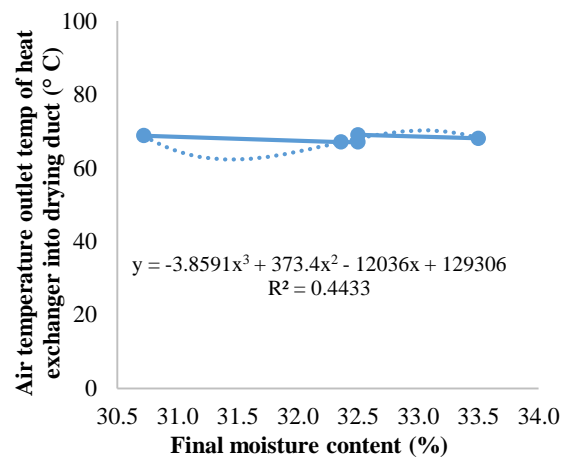


Figure 11. Effect of FMC on air temperature of heat exchanger (charcoal) for cornstarch

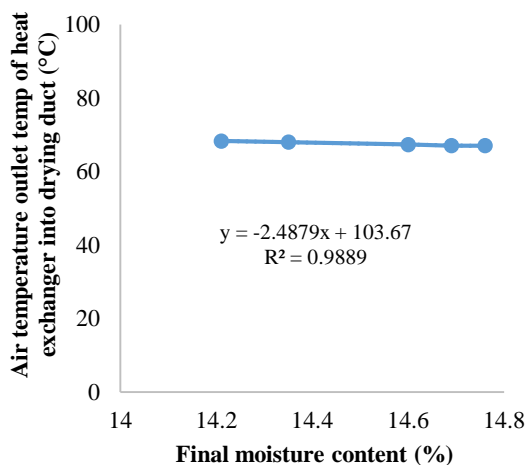


Figure 12. Effect of FMC on air temperature of heat exchanger (charcoal) for bean mash

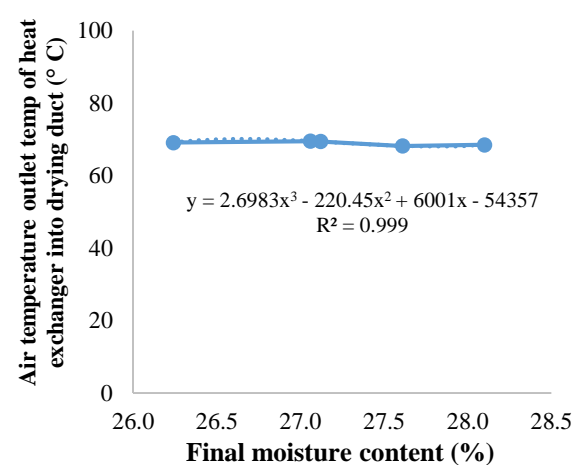


Figure 13. Effect of FMC on air temperature of heat exchanger (gas) for cassava mash

Figure 14 portrays the relationship between the FMC of cornstarch and the drying air temperature using charcoal as a source of fuel epitomized by R^2 of 0.4433. The lowest FMC of 30.75% was obtained at 68.95 °C. A steady decline in the air temperature dropped to 67.00 °C and a simultaneous increase in the FMC to 32.42%. The drying air temp was constant at FMC 32.42 - 32.50 %. An increase in drying air temperature from 67.00 – 69.00 °C at a constant FMC of 32.5%, followed by a dip to 68.00 °C at an FMC of 33.5%.

The association between FMC of bean mash and drying air temperature when charcoal is used for flash dryer is a very strong one as evidenced by R^2 of 0.9889 as shown in Figure 15. The least FMC was 14.23% at a peak air

temperature of 68.37 °C. It was observed that a continuous drop in drying air temperature was recorded with a corresponding increase in FMC.

The correlation between the FMC of cassava mash and air temperature when cooking gas is used as fuel is displayed in Figure 16 and supported by a near perfect R^2 of 0.999. It was observed that the lowest FMC of 26.23 % for cassava mash was attained at air temperature of 69.23 °C. It showed that at 69.47 °C, the FMC dropped 27.12 – 27.05 %. This was followed by a temperature drop to 68.38 °C at 27.6 % FMC before attaining a terminal temperature of 69.42 at a FMC of 28 %.

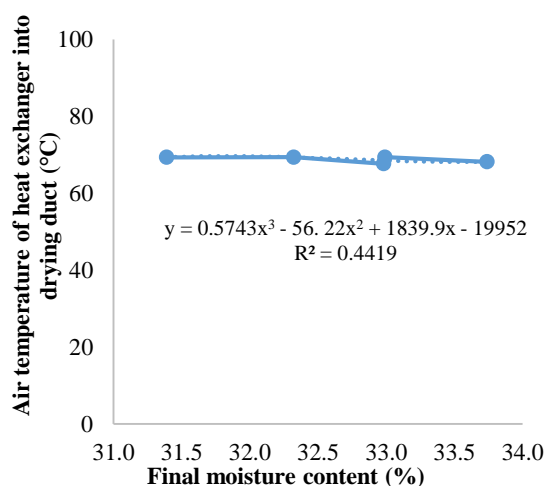


Figure 14. Effect of FMC on air temperature of heat exchanger (gas) for cornstarch

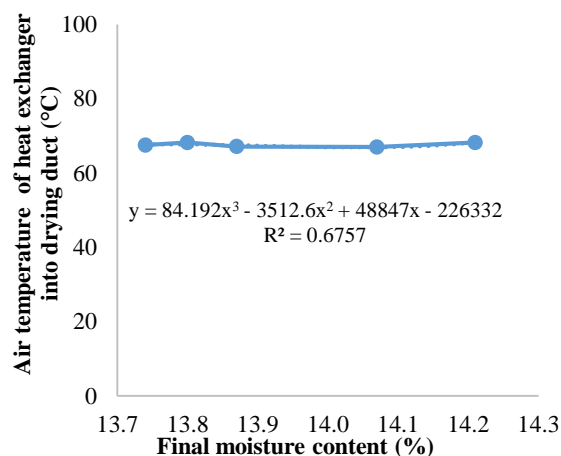


Figure 15. Effect of FMC on air temperature of heat exchanger (gas) for bean mash

Figure 17 shows the relationship between the FMC of cornstarch and the air temperature of heat exchanger using gas as a source of fuel with R^2 value of 0.4419. The lowest FMC of 31.4 % occurred at 69.38 °C. However, a temperature of 69.44 °C was recorded at 32.32 % FMC while latent activity occurred at 32.98 % with a 69.4 - 67.7 °C which was the lowest air temperature. The highest FMC of 33.74 % at a temperature of 68.2°C.

The association between the air temperature and the FMC of bean mash when cooking gas was used as fuel is portrayed in Figure 18 with a R^2 value of 0.6757. It was observed that the lowest FMC of beans mash of 13.74 % was obtained at a temperature of 67.5 °C. FMC was 13.80% at 68.2 °C air temperature. A sharp decline in temperature to 67.1 °C was observed at 13.87% FMC followed by slight dip to 67°C at 14.07 % FMC. The highest air temperature at 68.2 °C occurred at 14.21% FMC.

Relationship Between Drying Air Relative Humidity and Efficiency of Flash Dryer

The relationship between drying air relative humidity and the efficiency of a flash dryer is generally inversely proportional: lower relative humidity in the drying air leads to higher drying efficiency and faster evaporation rates and vice versa. However, the unpredictable nature of food during drying can lead to anomalies in the curves similar to Ju et al. (2024) as portrayed in Figures 19-24.

Figure 19 portrays the correlation between relative humidity of ambient air of the heat exchanger and the efficiency of flash dryer for cassava mash using charcoal as a fuel source supported by R^2 value of 0.9071. It was observed that a relative humidity of ambient air of 21.5 % yielded flash dryer efficiencies of 48.55 and 53.76 %. A dip in efficiency (53.7 %) was recorded as relative humidity increased from 21.50 to 22.5 %. Subsequently, the efficiency of flash dryer increased as relative humidity increased.

Figure 20 depicts the associativity between the relative humidity of ambient air of the heat exchanger and the efficiency of flash dryer on cornstarch, using charcoal as a fuel source. It was observed that the highest efficiency of flash dryer (74.93 %) was attained at 22.5 % ambient air relative humidity. Though, the pick-up efficiency of flash dryer at 64.12 % was at 21.48 % relative humidity which later increased to 68.6 % at the slight increase in relative humidity of 21.50 %. Efficiency of flash dryer was observed to be constant at 68.6 % as the relative humidity of ambient air ranged from 23.50 % to 24.01 %.

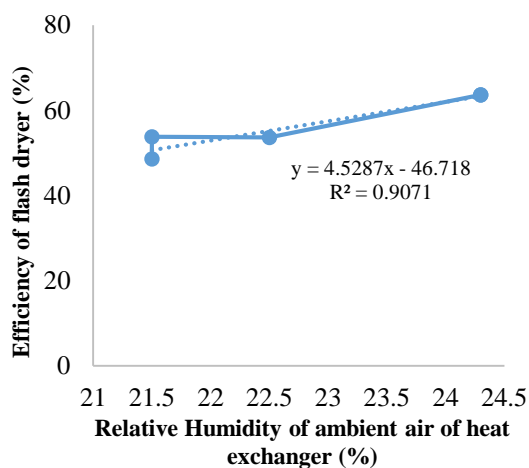


Figure 16. Effect of relative humidity on efficiency flash dryer (charcoal) for cassava mash

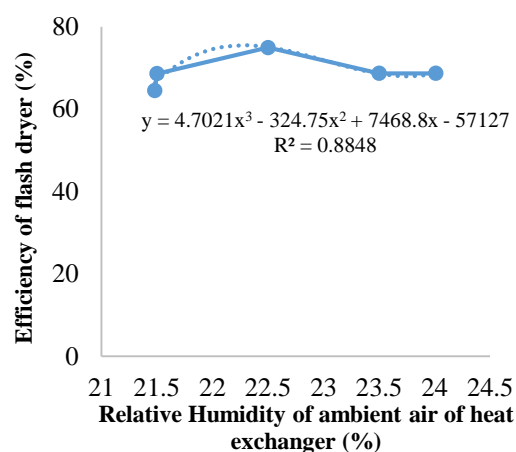


Figure 17. Effect of relative humidity on efficiency of flash dryer (charcoal) for cornstarch

Figure 21 displays the relationship between the relative humidity of the heat exchanger's ambient air and the efficiency of flash dryer on bean mash, using charcoal as fuel. This strong relationship was supported by R^2 value of 0.9972. It was observed that the initial efficiency of flash dryer at 58.28 % was recorded at 21.50 % relative humidity. The efficiency of flash dryer increased to 62.44 % at 22.3-22.5 % relative humidity. However, flash dryer efficiency initially dropped to 58.2 % at relative humidity of 23.53 % before slightly increasing to 58.28 % at 24.00 % relative humidity.

Figure 22 portrays the correlation between the relative humidity of the heat exchanger's ambient air and the efficiency of flash dryer for cassava mash, using gas as fuel, with an average correlation denoted by R^2 value of 0.5163. It was observed that the highest efficiency of flash dryer at 85.6 % preceding an initial efficiency of 81.9 % attained at 21.7 % relative humidity of ambient air. The efficiency of flash dryer was constant at 80.2 % at an increased relative humidity of ambient air of heat exchanger from 21.74 % to 23.2 %.

The associativity between the relative humidity of ambient air of heat exchanger and efficiency of flash dryer on cornstarch, using gas as fuel is strong represented by R^2 of 0.8686 and is presented in Figure 23. As observed, the highest efficiency of flash dryer was exhibited at 63.74 % at relative humidity of 21.58 %. At 58.27 % efficiency of flash dryer, the relative humidity was constant between 21.63 and 22.4 %. The least efficiency of flash dryer attained was 54.63 % at an increased relative humidity of 23.2 %.

Figure 24 defines the affiliation between the relative humidity of ambient air of heat exchanger and the efficiency of flash dryer for bean mash when powered by gas as excellent with R^2 value of 0.9244. The highest efficiency of drying bean mash attained was 58.28 % constant between 19.3 and 20.2 % of relative humidity. Afterward, the efficiency slightly decreased to 54.63 % observed at 21.2-22.3 % relative humidity of ambient air of heat exchanger before a slight increase to 56.46 % recorded at 23.1 %.

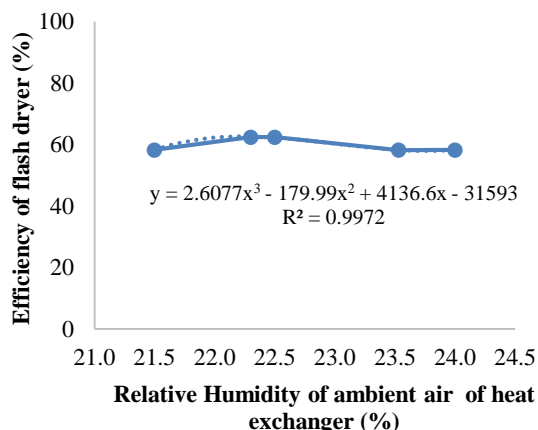


Figure 18. Effect of relative humidity on efficiency of flash dryer (charcoal) for bean mash

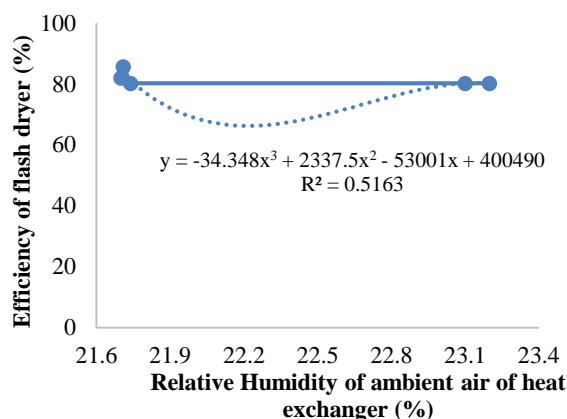


Figure 19. Effect of relative humidity on efficiency flash dryer (gas) for cassava mash

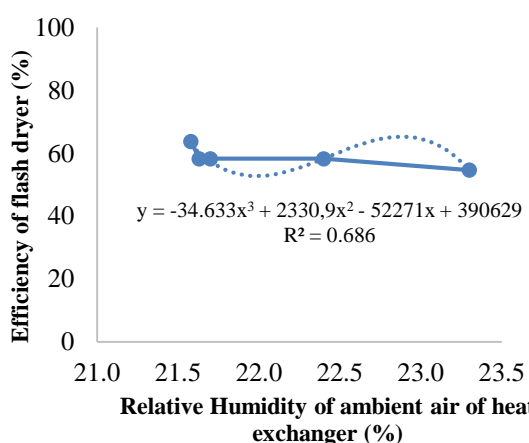


Figure 20. Effect of relative humidity on efficiency flash dryer (gas) for cornstarch

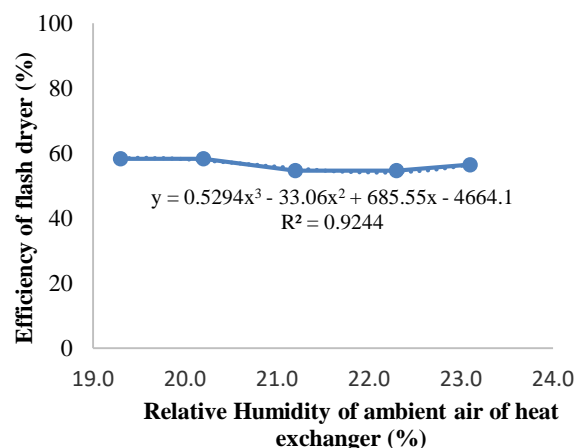


Figure 21. Effect of relative humidity on efficiency flash dryer (gas) for bean mash

Relationship Between Drying Air Temperature and Efficiency of the Heat Exchanger

The relationship between the temperature of the drying air and the efficiency of the heat exchanger is generally direct with an increment in temperature resulting in an increment in efficiency and vice versa as described in Adegbite et al. (2023) and displayed in Figures 25-30.

Figure 21 describes the relationship between the air temperature and the efficiency of the heat exchanger for cassava mash using charcoal as fuel as perfect evidenced by R^2 value of 1. As observed, the efficiency of heat exchanger at 80.4% was constant throughout for all values of air temperature. Figure 22 shows the correlation between the air temperature of heat exchanger and the efficiency of the heat exchanger for drying corn mash using charcoal as fuel, a controversial correlation not denoted by R^2 . It was observed that the efficiency of heat exchanger was constant at 56.00 % at all values of air temperature. Figure 23 illustrates the connection between both the air temperature and the efficiency of heat exchanger in drying bean mash using charcoal as fuel as a neutral one with R^2 value of 0. It was observed that the efficiency of heat exchanger at 60.32 % was constant as air temperature of heat exchanger varied from 67.02 °C to 68.3 °C. Figure 24 portrays the correlation between the air temperature and efficiency of the heat exchanger for drying cassava mash when gas was used as fuel with an inconsistent R^2 value. It was observed that the efficiency of heat exchanger at constant value 57.90 % was attained at the air temperature of heat exchanger between 68.20 °C to 69.50 °C.

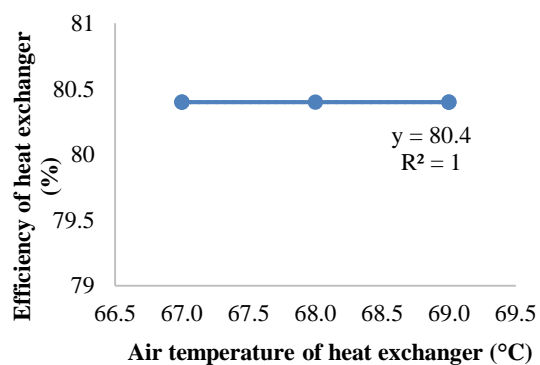


Figure 22. Effect of air temperature on efficiency of heat exchanger (charcoal) for cassava mash

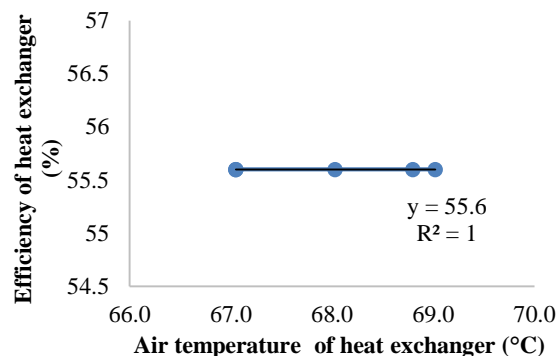


Figure 23. Effect of air temperature on efficiency of heat exchanger (charcoal) for corn starch

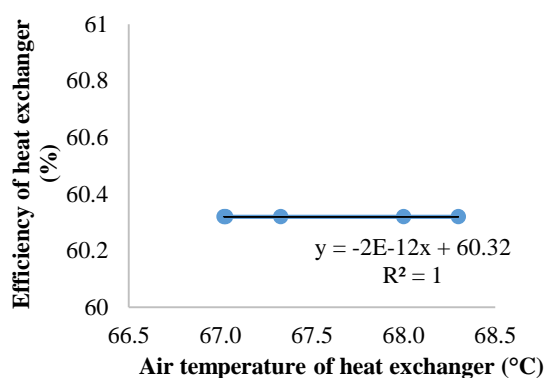


Figure 24. Effect of air temperature on efficiency of heat exchanger (charcoal) for bean mash

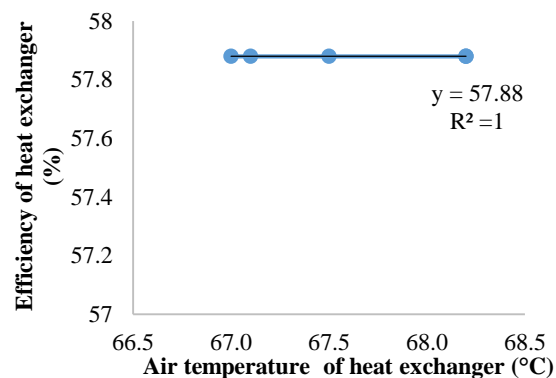


Figure 25. Effect of air temperature on efficiency of heat exchanger (gas) for cassava mash

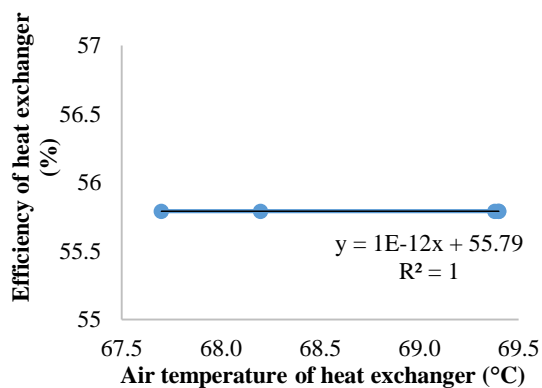


Figure 26. Effect of air temperature on efficiency of heat exchanger (gas) for cornstarch

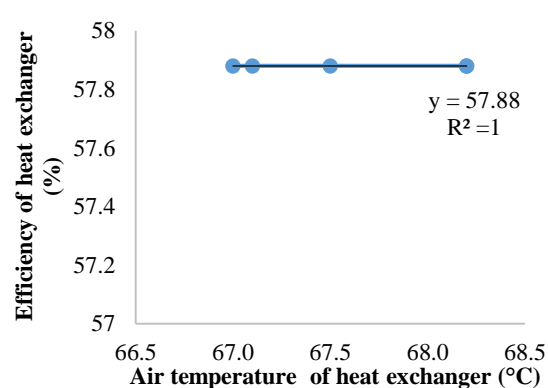


Figure 27. Effect of air temperature on efficiency of heat exchanger (gas) for bean mash

The relationship between the air temperature and efficiency of the heat exchanger while drying cornstarch using cooking gas as fuel is displayed in Figure 25 with a negative R^2 value (-1). It was observed that the efficiency of heat exchanger was constant at 55.79 % was attained at the air temperatures 67.7- 69.40 %.

Figure 26 depicts the associativity between the air temperature and the efficiency of heat exchanger while drying bean mash with cooking gas as a source of fuel with an unidentified R^2 value. The efficiency of heat exchanger was observed to be constant at 57.88 % for air temperatures of ranging from 67.0 °C to 68.20 °C.

Conclusion

The mini multipurpose flash dryer was designed, fabricated and evaluated for its performance on different batches of measurable variables. The machine has an average drying efficiency of 81 % for cassava mash, 69 % for cornstarch and 59 % for bean mash respectively. The machine fabricated requires minimum maintenance and can be disassembled for transportation.

The following conclusions can be deduced from the results:

- (i) The buffer section of the drying duct positively influenced the time taken for drying of food samples.
- (ii) The moisture content of food samples induced variations at all level of drying.
- (iii) The machine was able to dry all the selected food samples into powdered form except the bean mash.

Based on the results obtained, the following are recommended for future research:

- (i) Speed variations could be considered for proper optimization of the drying operation.
- (ii) Heat exchanger could be lagged to avert excessive heat loss by conduction.
- (iii) More buffer sections could be incorporated to enhance the efficiency of the flash dryer on each food sample.
- (iv) Food condiments and spices such as locust beans, nutmegs etc. can also be milled, dried and sold.

Conflict of Interest

The author(s) declare that there is no conflict of interest regarding the publication of this manuscript.

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