6TH International Conference and Workshop on Engineering and Technology Research (ICWETR) LAUFET 2025: 181-194

Varietal and Temperature Effects on Exergy/Energy Analysis for the Drying of Plantain/Banana Fruits and the Nutritional Quality of its Flours

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ABSTRACT

Musa species also known as banana plant is an important staple crop that contributes to the calorie and subsistence economies in Africa. Plantain flour, a shelf stable food product from the fresh fruit of the species is a rich source of nutrient and well patronized in West Africa. However, using both plantain and banana to produce flour was due to their similarity in properties, making the flour of both more abundant and thereby decreasing the cost. The energy involved in the production during drying is an important factor determining the cost of production. Hence, the analysis of the energy and exergy of the process needs to be carried out to optimize the energy input. This study determined the effect of drying temperature and varieties on the energy/exergy analysis of the drying and the nutritional values of plantain. Plantain and banana were washed, peeled, and sliced into uniform measurements of 3 mm thickness, 5 mm long, and 4 mm wide. The samples were then divided into two portions each, the first portion was dried with an oven dryer at the temperatures of 50, 60, and 70 °C and the remaining portion was sun dried. The sliced samples were dried, milled, and then packed in the cellophane bag for further analysis. The energy/exergy analysis on drying was analyzed and dried samples were evaluated for proximate analysis and vitamins. The energy utilization ranged from 34.13 to 40.38 kJ/s, 73.37 to 78.72 kJ/s, and 120.72 to 127.94 kJ/s for temperatures 50, 60 and 70 °C, respectively. The exergy inflow varied between 2.14 and 10.39 kJ/s as the temperature increased from 50 to 70 °C. The result showed that plantain samples dried faster than other varieties. The carbohydrate increases while the protein, ash, fat, fiber, and vitamins of plantain flour decrease with an increase in temperature.

Keywords:

Energy utilization,
Exergy,
Plantain,
Banana

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INTRODUCTION

Plantain (Musa paradisiaca) falls under the banana family, and it is a monocotyledon perennial and important staple food grown in sub-Saharan Africa (Baiyeri et al., 2011). It is one of the most important sources of food energy in West and Central Africa, where about 70 million people derive more than 25% of their calories from plantains (IITA, 2014). They are good sources of carbohydrates and rich in vitamins A, C, and B and minerals such as calcium and iron. They provide around 35% of the total calories in the diets of more than 14 million people in the sub-Saharan region (Abiodun-Solanke and Falade, 2010). Plantain and other banana family species vary in their sugar and starch content proportions; plantains are those with high starch content and are eaten after cooking. Plantain is eaten boiled, roasted, stewed, or made into porridge and also processed into flour (Sampath et al., 2012). Currently, unripe plantain flour is being processed into a thick paste product known as amala, which is medically recommended for diabetic patients (Adenekan et al., 2021).

Banana was reported to have more extracted starch yield compared to starch yield from plantain cultivars (Eraga *et al.,* 2016). Bananas are varieties of the Musa species with high sugar content and are eaten fresh or cooked. Since hydrolysis, the process by which starches are converted to sugars, acts fastest in the fruit with higher moisture content. Banana converts most of their starch into soluble sugar at ripening, unlike plantains, where starch is partially broken down (Gao *et al.,* 2016). It contains lower levels of dry matter, ascorbic acid and starch than the plantain varieties. Both plantains and bananas are reported to contain vitamins A, B, B6, C and B12, as well as minerals (Pereira and Maraschin, 2015). Fresh plantain could be preserved by the use of chemical preservatives, controlled or modified atmosphere. However, these technologies are not utilized among the smallholder farmers in underdeveloped countries, who may find these technologies not economically feasible. Plantain and banana are seasonal and highly perishable crops and many attempts have been made to produce stable and storable products from the plantain fruit. Plantain may be processed into many products at different stages of physiological maturity, unripe, ripe, and overripe, in several ways such as frying, grilling, boiling, and drying. Ripe banana powder is used for processed foods such as infant diets, noodles, in the bakery and confectionery industries and in the treatment of intestinal disorders (Sahoo *et al.,* 2014).

According to Berk (2009), drying promotes an addition of value to bananas besides preservation. Drying is the unit operation involved in the removal of moisture content under controlled conditions, such as pressure, temperature, and volume, to prevent microbial activities. Moisture removal from plantain seems to be an appropriate and economical means of preservation, resulting in shelf-stable and convenience products. In essence, large quantities of food products are dried to improve shelf life, reduce packaging costs, lower weights, enhance appearance, retain original flavour, and maintain nutritional value (Rahman, 2020). The parameters affecting the drying of crops are the drying air temperature, relative humidity, and velocity, in addition to the product's initial moisture content. Drying food materials takes a lot of energy and is time-consuming. In this regard, exergy can be interpreted as the maximum amount of work that can be produced by a stream of matter, heat, or work as it comes to equilibrium with a reference environment (Terzi, 2018). It is then the energy that is available to be used. In the drying industry, the goal is to use a minimum amount of energy for maximum moisture removal for the desired final conditions of the product. Therefore, this work concentrates on the energy and exergy analyses for the drying of plantain, ash plantain and banana by using a conventional oven-type dryer, as this might help to enhance the economic productivity of the food processors.

MATERIALS AND METHODS

Materials

Matured green plantain (*False horn*), ash plantain (hybrid), and banana (*Cavendish*) were obtained from a local market in Ogbomoso. Equipment used includes trays, a weighing scale, a knife, a vernier caliper, a conventional oven, and a thermometer.

Sample Preparation

The plantain and banana were washed in a clean bowl and then peeled. They were sliced into uniform thickness measurements of 3 mm, 5 mm long, and 4 mm wide. The sliced banana and plantain were then divided into two portions each and placed into air conventional oven drier and the remaining portion was sun-dried.

Drying Procedure

The sliced plantain/banana was arranged in an oven tray and placed in the oven, which was adjusted to 50 ℃ (Tunde-Akintunde, 2014). After 30 min, the inlet, outlet, and ambient temperatures for the drying chamber were measured and recorded. Also, the inlet, outlet, and ambient temperatures for the dry bulb and wet bulb temperatures were measured and recorded to obtain values for relative humidity by using a psychometric chart. The readings of the weight of each sample were taken and accurately recorded every 30-minute interval for the first four hours and then 1 hour until a constant weight was achieved. The sliced banana and plantain were dried, milled, and then packed in the cellophane bag for further analysis. This procedure was repeated for temperatures of 60 and 70 ℃ and the measurement taken was recorded.

Proximate Composition Determination

Moisture content: The moisture content of each sample was determined by weighing 2 g of each sample into a moisture dish. The samples were dried at 105 ℃ for 5 h (in triplicate) and weighed. It was then dried continuously and weighed at each hour until a constant weight was attained. The loss in weight was reported as moisture content (AOAC, 2005), which was then calculated as follows:

$$\mathrm{M.C}\ (\%) = \frac{W_i - W_d}{W_i} \times 100 \quad (1)$$

where, W_i = Weight of sample before drying and W_d = Weight of sample after drying

Ash content: The sample (2 g) was placed in a muffle furnace and was ashed at 550 ℃ for 5 h. The residue was then weighed and the difference in weight before and after ashing was calculated (AOAC, 2005).

$$Ash\ content\ (\%) = \frac{W_1 - W_2}{W_3} \times 100 \quad (2)$$

where, W_1 = weight of crucible + ash, W_2 = weight of empty crucible and W_3 = weight of sample

Protein: Protein was determined using the Kjeldahl method (AOAC, 2005). The sample (0.2 g) was weighed into a digestion tube and 0.2 g of the catalyst tablet was added. This was dispersed carefully in about 10 ml of concentrated (H_2SO_4) sulphuric acid in the digestion tube. The mixture was heated in the digestion chamber till a clear, homogenous mixture was obtained and was distilled and titrated against 0.1N HCl. The percentage protein was calculated using Equation 3:

$$Ash\ content\ (\%) = (1.40\ x\ M\ x\ Titre\ Value)/Weight\ of\ sample \quad (3)$$

Conversion factor = 6.25

Fat content: The crude fat of the mixture was determined by the intermittent extraction method in a Soxhlet apparatus (AOAC, 2005). The flour sample (5 g) was weighed into a thimble and placed in the Soxhlet extractor. the round bottom flask was weighed and petroleum ether was poured into it. This was then extracted for 5 h and excess petroleum ether evaporated off. The flask was placed in an oven for 30 min, cooled, and weighed. The difference in final and initial weight was expressed as the percentage fat content.

$$Crude\ Fat\ (\%) = \frac{W_2 - W_1}{W} \times 100 \quad (4)$$

where W is the weight of the sample; W_1 is the weight of the flask + sample after extraction, and W_2 is the weight of the flask + sample after drying.

Fiber: Three grams (3 g) of the sample was air dried and transferred to a dry 100 ml conical flask, 200 ml of H_2SO_4 was added and boiled. It was allowed to boil gently for 3 min, maintaining a constant volume with the use

of a condenser. It was rotated every minute to mix the content and remove particles. A Buckner funnel filled with filter paper was prepared, boiling water was poured inside, and then allowed to boil for 30 min. The acid mixture was allowed to stand for 1 min and then poured immediately into the layer of hot water under a gentle stream in the funnel. The section was adjusted to complete the titration of a 200 ml bottle within 10 min. Insoluble matter was washed with boiling water to remove every acid present; the washing was done into the original flask using a wash bottle containing 200 ml NaOH solution and was boiled. The boiling proceeded for 30 min and then filtered immediately through a filter paper. The insoluble material was first washed off with water, then with ammonium chloride, and finally with boiling water until it was free from acid. The insoluble matter was transferred to a dried, weighed filter paper and was then dried at 100 ℃ until a constant weight was achieved (AOAC, 2005).

$$Crude\ Fat\ (\%) = \frac{W_1 - W_2}{W_3} \times 100 \quad (5)$$

where, W_1 is the Initial weight of flask + sample; W_2 = Final weight of flask + sample; W_3 = Weight of sample

Carbohydrate: Carbohydrate content was calculated by difference as expressed in Equation 6 (AOAC, 2005):

$$Carbohydrate(\%) = 100 - (moisture + ash + crude + protein + fat + fibre) \quad (6)$$

Vitamin C and β-carotene Determination

Vitamin C was determined by the dyestuff titration method. A Sample (5 g) was digested with 0.4/100 g oxalic acid. The aliquot was titrated against dyestuff, which was previously standardized by a standard ascorbic acid solution, and the vitamin C content was calculated by expression.

$$Vitamin\ C\ (mg/100\ g) = (Titre\ Value\ x\ 0.606\ x\ 100)/Weight\ of\ sample \quad (7)$$

The β-carotene content of the samples was estimated using reversed-phase high-performance liquid chromatography (HPLC) (Rohmah *et al.,* 2021). Homogenized juice of 120 µL was extracted with 500 µL of hexane. The mixture was vigorously shaken on an electronic shaker for 4 min, centrifuged for 2 min at 10,000 rpm and the supernatant pooled. The extraction process was repeated. The pooled supernatant was evaporated to dryness under Nitrogen gas and redissolved in 120 µL mobile phase. The resulting aliquot (120 µL) was then injected into the HPLC (C- R6A Chromatopack, Shimadzu Corporation, Japan) column with ultraviolet detection (UV- VIS) spectrophotometric detector at 450 nm. A standard was prepared and chromatographed. Areas corresponding to the standard retention time were identified and used in the estimation of vitamin A content in samples.

Energy Analysis

The energy utilization (EU) was calculated by using the following equations:

$$EU = m_{da}(h_{dai} - h_{dao}) \quad (8)$$

The energy utilization ratio (EUR) of the drying chamber was also estimated by applying the Midilli and Kucuk (2003) equation 9, given as:

$$EUR = \frac{m_{da}(h_{dai} - h_{dao})}{m_{da}(h_{dai} - h_{dae})} \quad (9)$$

where, m_{da} is the mass flow rate; h_{dai} is the inlet enthalpy; h_{dao} is the outlet enthalpy; and h_{dae} is the ambient enthalpy

Humidity ratios were obtained by using a psychometric calculator.

Exergy Analysis

Based on the second law of thermodynamics, total exergy inflow, outflow and losses in the drying chamber were estimated by determining the exergy values at steady and unsteady states (Akpinar *et al*., 2006; Midilli and Kucuk, 2003). The exergy values were calculated by using the characteristics of the working medium from a first-law energy balance. However, the general form of the exergy equation applicable for steady flow systems (Midilli and Kucuk, 2003) was employed, which implies;

$$\text{Exergy} = m_{da} c_{pda} \left[(T - T_{ref}) - T_{ref} \ln \frac{T}{T_{ref}} \right] \quad 10$$

$$\text{Exergy inflow} = m_{dai} c_{pdai} \left[(T_i - T_{ref}) - T_{ref} \ln \frac{T_i}{T_{ref}} \right] \quad 11$$

At the outlet, subscript (o) denotes outlet conditions in Equation 12:

$$\text{Exergy outflow} = = m_{dao} c_{pdao} \left[(To - T_{ref}) - T_{ref} \ln \frac{T_o}{T_{ref}} \right] \quad 12$$

According to Akpinar *et al.* (2006), Equations 13 and 14 were used in estimating the exergy efficiency as follows:

$$\text{Exergy loss} = (\text{Exergy inflow} - \text{Exergy outflow}) \quad 13$$

$$\text{Exergy Efficiency} = (\text{Exergy inflow} - \text{Exergy outflow})/\text{Exergy inflow} = 1 - \text{Exergy loss} / \text{Exergy outflow} \quad 14$$

where, c_{pda} = specific heat capacity; T_i = inlet temperature; T_o = outlet temperature; and T_{ref} = reference temperature

RESULTS AND DISCUSSION

Drying Characteristics of Plantain

The drying kinetics of plantain slices, ash plantain and banana are as shown in Figures 1 and 2, where moisture content is represented along drying time for air temperatures between 50 and 70 ℃. It was observed that moisture content decreased with increasing drying time, as evidenced by the downward slope of the curves depicting a reduction in moisture content as drying time increased in Figure 1. As the sample dried, the moisture present inside it moved to the surface and evaporated, thereby leading to a decrease in the moisture content of the sample. The decrease in moisture content was faster at the initial stage of drying and then slower as drying continued. Many food materials have been reported to have decreasing moisture content with an increase in drying time (Salehi and Satorabi, 2021). The rate at which moisture content decreases was found to be fastest at 70 ℃ for plantain samples and slowest at 50 ℃ for banana variety samples. Also, this is because moisture migrates faster to the surroundings at higher temperatures.

The drying rate decreased from 0.08 to 0.002667 g/water min for samples at 50 ℃ and 0.08 to 0.000167 g/water min for samples at 70 ℃, as shown in Figure 2. From this study, the temperature of 70 ℃ has the highest drying rate, followed by 60 and 50 ℃. As expected, the increase in drying temperature resulted in a significant increase in drying rate. This observation was also reported by Kumar *et al.* (2019) for the convective drying of banana. There was also a decrease in the drying rate with an increase in the drying time. As the moisture content decreased with time, the drying rate also decreased. The drying rate was initially higher because the evaporation of water comes from regions near the surface. This trend could be due to the removal of free moisture near the surface of

the plantain slices at the early stages of drying.

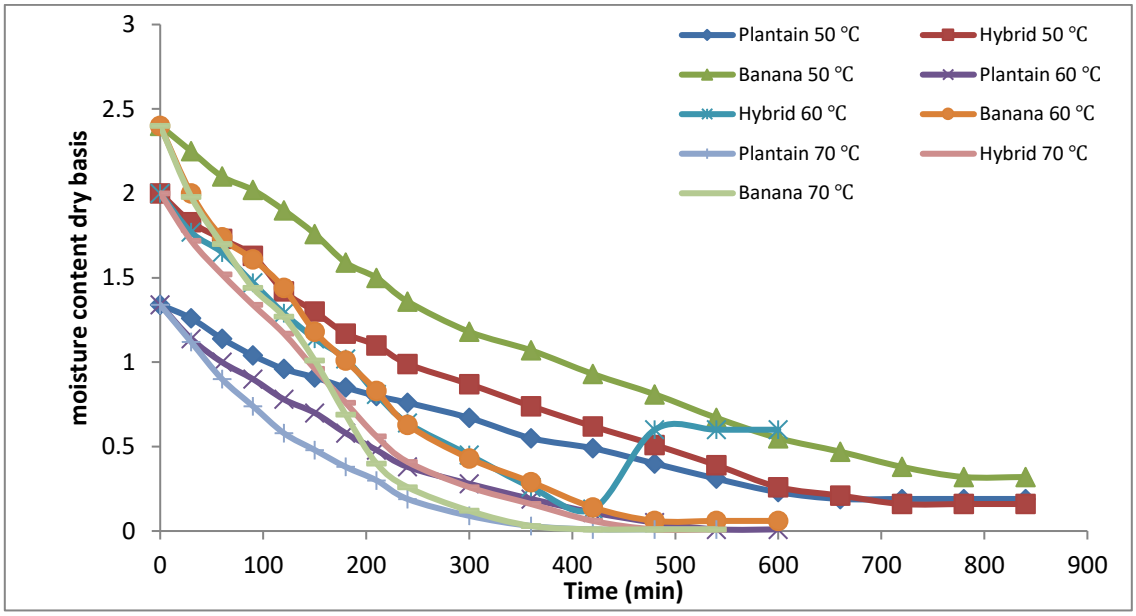

Figure 1: Moisture content against drying time for samples at temperatures of 50, 60 and 70 °C

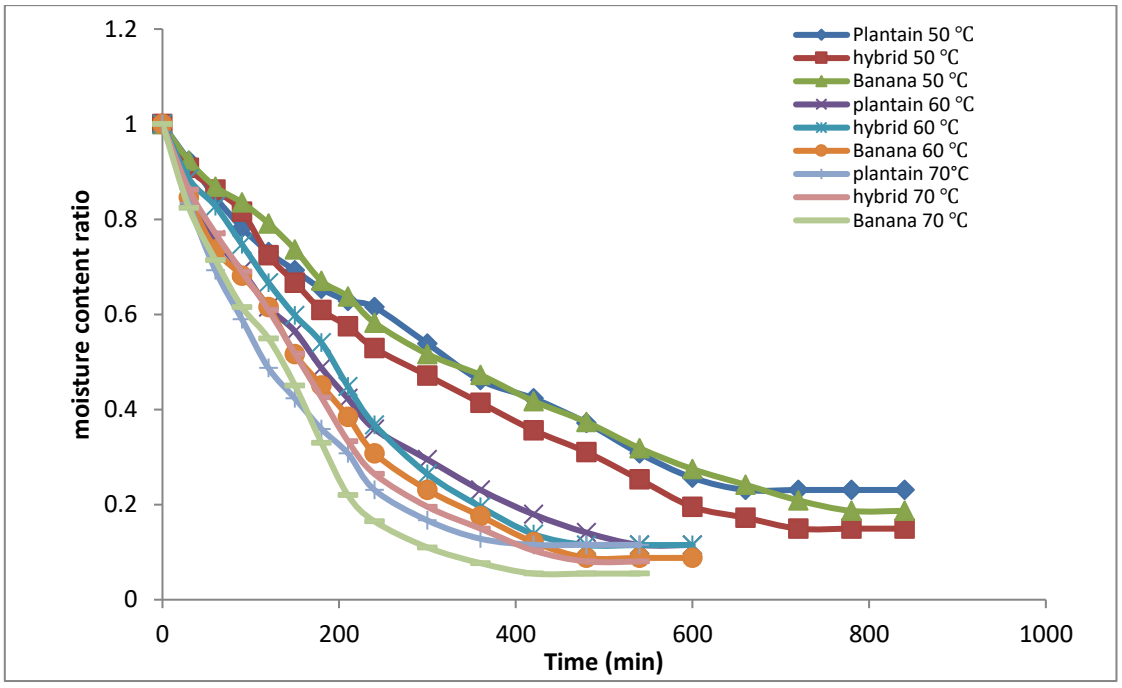

Figure 2: Drying rate as a function of drying time for samples at temperatures of 50, 60 and 70 °C

As drying progressed, the drying rate decreased with a decrease in moisture content, because the water to be evaporated comes from parenchymal cells within the structure and must be transported to the surface. This indicates that the free water has been evaporated, leaving the bound water. The falling rate region is indicative of an increased resistance to both heat and mass transfer through the inner cell (Kashaninejad *et al*., 2007).

Energy Analysis

The energy analysis of the drying process of plantain was performed by using data obtained from experiments. Figure 3a shows the variation of energy utilization (EU) as a function of drying time for different drying temperatures and varieties of banana. Energy utilization values ranged from 3.86 to 40.38 kJ/s, 59.73 to 78.72 kJ/s, and 87.22 to 127.94 kJ/s for drying samples at temperatures of 50, 60 and 70 ℃, respectively. The energy utilization at 50 ℃ varied from sample, and the maximum EU value of 40.38 kJ/s was obtained during the drying of banana variety, followed by the value of 36.02 kJ/s obtained from the drying of plantain hybrid and the least value of 34.13 kJ/s was obtained for drying of plantain samples.

The same trend of the result was obtained at 60 ℃, where the highest EU of 78.72 kJ/s was obtained from the drying of banana, followed by the value of 75.94 kJ/s obtained from the drying of plantain hybrid and the least value of 73.37 kJ/s was obtained for the drying of plantain samples. At 70 ℃, the highest EU was obtained for the banana variety sample (127.94 kJ/s), next to this was the plantain hybrid sample with an EU value of 123.68 kJ/s, while the lowest EU value of 120.72 kJ/s was obtained for the plantain. The analysis showed that the EU increased with increasing air temperature from 50 to 70 ℃ for the plantain and other banana varieties because the amount of energy supplied to the system increases with temperature. The EU increase with temperature was due to high input enthalpy and fast heat and mass transfer rate (Beigi *et al,.* 2021).

The differences in energy values for the varieties can be attributed to the differences in chemical composition and cellular structure. It was also observed that energy utilization decreased with increasing drying time at the initial stage of drying as a result of a larger amount of energy supplied. As the drying time increases, the amount of energy utilized from the energy being supplied reduces since the heat needed to evaporate the remaining moisture content of the samples has decreased. Figure 3b shows the variation of energy utilization ratio (EUR) as a function of drying time for different drying temperatures and samples. The EUR ranged from 0.090 to 1.157, 0.566 to 0.996, and 0.555 to 0.814 for drying samples at temperatures of 50, 60 and 70 ℃, respectively. From the data obtained, it was observed that the EUR decreased with an increase in drying temperature from 50 to 70 ℃. Comparing the three temperatures, a maximum value of EUR was obtained at 50 ℃, followed by that obtained at 60 ℃, with the least EUR obtained at 70 ℃. T

hese values show that the EURs of the drying chamber decreased with the increase in temperature of the drying air. At 50 ℃, a maximum value of EUR of 1.157 was obtained for banana variety, a value of 0.843 for the plantain hybrid, while the lowest EUR value of 0.798 was obtained for plantain. The same trend of results was obtained for samples at 60 and 70 ℃, respectively. A minimum value of EUR was obtained at 70 ℃, where the EUR value of 0.814 was obtained for the banana variety, a value of 0.787 was obtained for the plantain hybrid and a value of 0.768 was obtained for the plantain sample. The values of EUR were low for different conditions of drying.
This means that the energy is still available at the outlet.

The exergy analysis of the thin layer drying process of plantain, hybrid, and banana was performed by using data obtained from the experiments, and the results obtained from these calculations are presented in Figures 4-5. The exergy inflow is shown in Figure 4a and it varied between 2.14 and 10.39 kJ/s as the drying temperature increased from 50 to 70 ℃ with an air velocity of 1.55 m/s. A maximum value of exergy inflow of 10.39 kJ/s was obtained at a drying air of 70 ℃ and a minimum value of exergy inflow of 2.14 kJ/s was obtained at a drying air of 50 ℃.

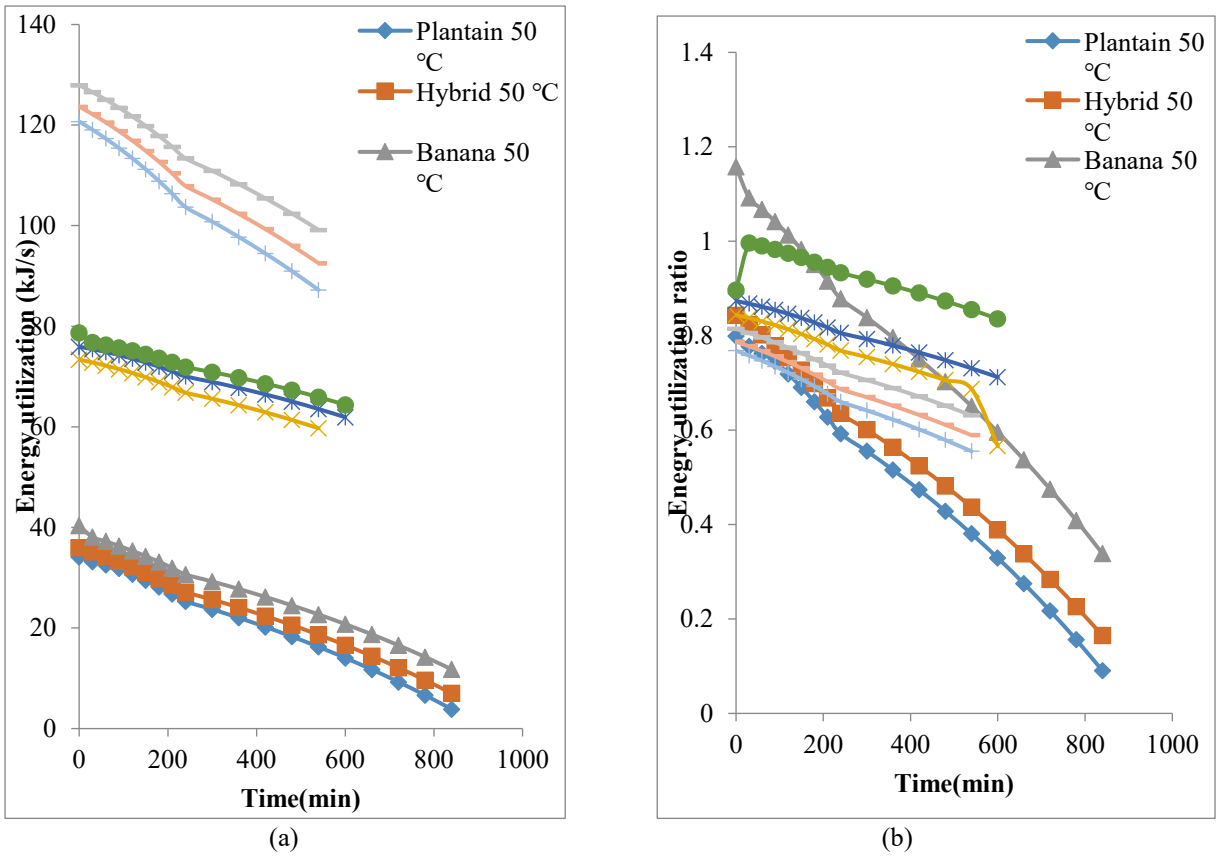

Figure 3: (a) Energy utilization, (b) utilization ratio as a function of drying time for plantain, hybrid, and banana varieties at 50, 60, and 70 °C.

The maximum exergy is observed at the beginning of the drying process when there is maximum moisture evaporation from the samples. This signifies that the energy supplied by the dryer at high temperature is not fully utilized by the product during the drying experiment**.** Figure 4b shows the exergy outflow as a function of drying time for different air temperatures. The value of exergy outflow decreased with increasing drying time. It was observed that the exergy outflow maximum value of 3.93 kJ/s was obtained for plantain slices at a drying temperature of 70 °C, while the minimum value of exergy outflow of 0.84 kJ/s was obtained for the banana variety at a drying temperature of 50 °C. The result shows that a small amount of energy is used, which means that energy is still available at the outlet.

Figure 5a shows exergy loss as a function of drying time for the different samples at different drying air temperatures. Analysis showed that values of exergy loss increased with increasing drying time and temperature. Comparing the three temperatures, the highest exergy loss was obtained at 70 °C, while the lowest value was obtained at 50 °C. At 50 °C, exergy loss varied with the highest value obtained for the banana (1.29 kJ/s) and the least for the plantain samples (0.95 kJ/s). Similar results were obtained for temperatures of 60 and 70 °C. The increase in exergy loss was due to more moisture evaporation, which caused a reduction in exergy at the outlet airflow. A similar finding was reported by Liu *et al*. (2019) for hot air impingement drying of mushroom slices.

Figure 5b shows the variation of exergy efficiency as a function of time at different air temperatures for plantain, hybrid, and banana samples. Analysis showed that the value of exergy efficiency decreased with increasing drying time. It was also observed that the exergy efficiency increases as the drying temperature increases.

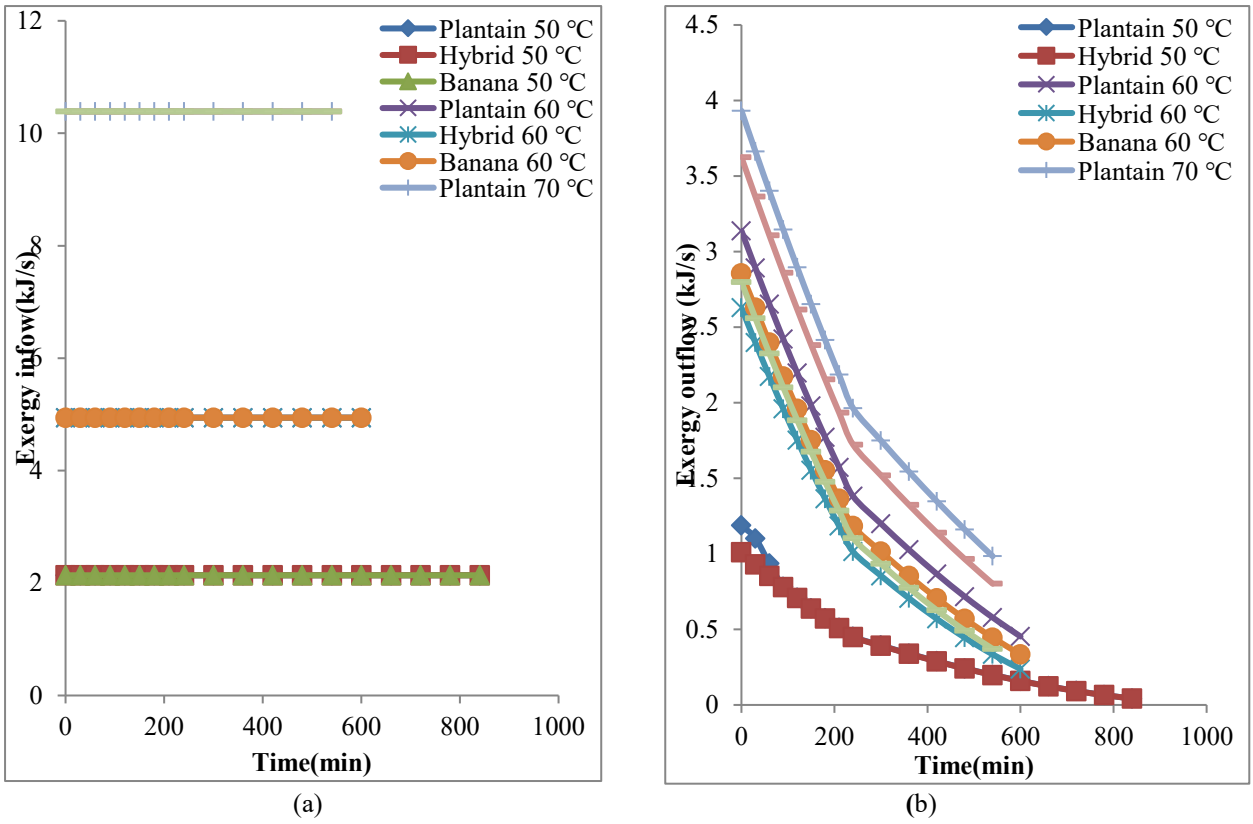

Figure 4: (a) Exergy inflow, (b) Exergy outflow as a function of drying time for samples at temperatures of 50, 60 and 70 °C

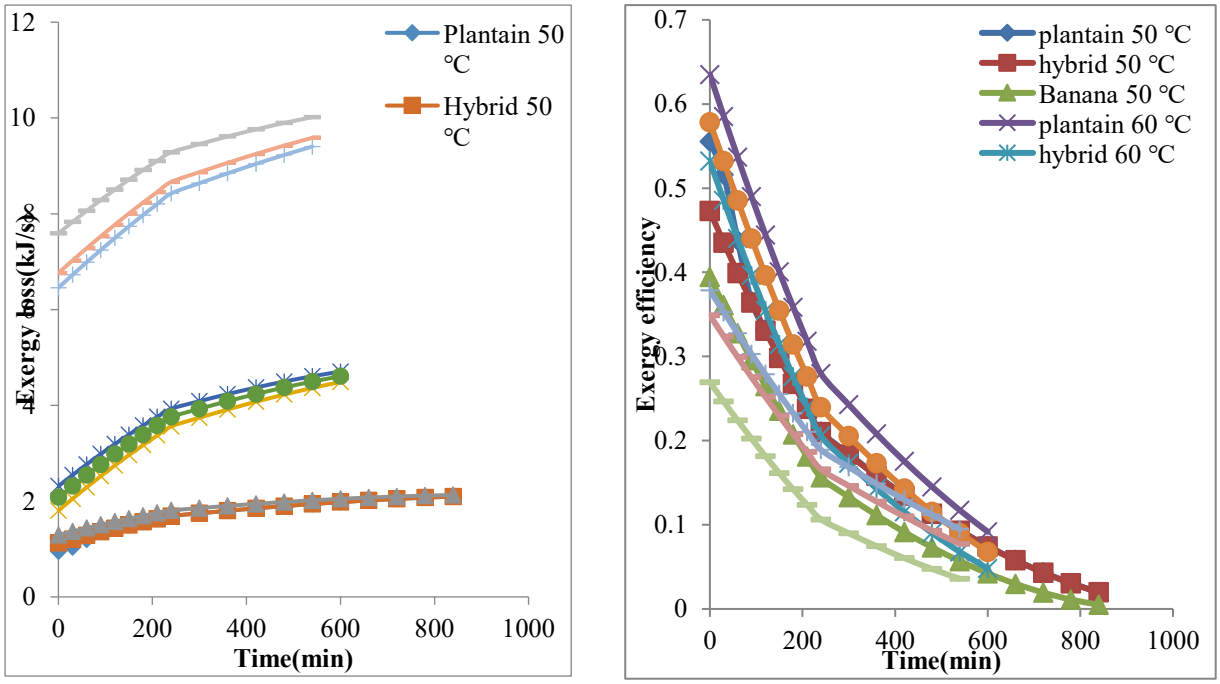

Figure 5: (a) Exergy loss, (b) Exergy efficiency as a function of drying time at temperatures of 50, 60, and 70 °C.

Comparing the three drying air temperatures, the maximum exergy efficiency value of 0.64 was obtained for the plantain sample at 60 ℃, while the least value of 0.005 was obtained at 50 ℃ for the banana sample. At 50 ℃, exergy efficiency varied in samples, with a maximum value of exergy efficiency obtained for the plantain and the least for the banana. Similar results were obtained for 60 and 70 ℃. An increase in exergy efficiency was expected due to the fact of higher exergy loss at higher temperatures (Corzo *et al.* 2008). This finding was in agreement with Aviara *et al.* (2014) for tray drying of cassava starch. The exergy efficiency was found to be higher at the initial stage of the drying process but decreased steadily as drying continued. This identifies the exergy outflow of the dryer system as the major site of thermodynamic inefficiency, showing that a large portion of the thermal exergy supplied is lost in the outlet air, which represents a serious disadvantage for this drying system. The other sources of inefficiency include exergy loss. The exergy loss occurs in cases where the temperature boundary of the dryer is higher than the ambient temperature; thus, avoiding heat transfer across the boundary of the system can reduce the exergy loss.

Effect of Drying on the Proximate Composition of Plantain and Banana Flour

The results obtained from the proximate analysis of the dried samples are shown in Table 1. Significant differences were found in the samples. The moisture content decreased with increased temperature; a maximum value of moisture content of 12.59% was obtained at 50 ℃, while a minimum value of 7.98% was obtained at 70 ℃ due to high temperature. The result indicates that flour obtained from the hybrid at the highest temperature may have a better-keeping quality due to low water content compared to other plantain flour samples. The protein content of the dried samples ranged from 9.63 to 14.88% and it decreased with an increase in temperature. This implies that plantain is not rich in proteins. This result agrees with the report by Salawu *et al*. (2015) on unripe plantain powder.

The carbohydrate increased with an increase in temperature, where the maximum value of 76.23% of carbohydrates was obtained for banana at 70 ℃ and the minimum value of 62.94% was obtained for banana at 50 ℃. Comparing sun-dried samples, the maximum value of 59.22% was obtained for the hybrid and a minimum value of 55.39% was obtained for plantain. This trend, aligned with the work of Doymaz (2010), showed that banana and plantain contain enough amounts of carbohydrates and a low amount of protein. The ash content ranged in value from 8.32 to 4.96% for oven-dried samples at temperatures of 50 to 70 ℃ and 9.86 to 8.77% for sun-dried samples. The ash content indicates the presence of minerals in the samples. The ash decreased with an increase in drying temperature.

Fat, indicating the total lipid content of the plantain as shown in Table 1, ranged in value from 1.01 to 1.83% for oven-dried samples at temperatures of 50, 60, and 70 ℃ and 1.98 to 2.11% for sun-dried samples. Variations in the fat content of samples could be due to the heat intensity during the drying process. The fat decreased with an increase in drying temperature. The decrease in lipid content of the samples could be a result of lipid oxidation. This is because lipid oxidation is known to be increased by many factors such as heat, sunlight and radiation (Mandal *et al*., 2014).

Effect of Drying on the Retention of Vitamin C and β-carotene

The effects of the drying conditions on the degradation of vitamins C and A at the temperatures of 50 and 60 ℃ are shown in Table 2. The data shows that the degradation of vitamin C and β-carotene in the dried samples is considerably affected by the drying conditions and an increase in air temperature. Similar behaviours were

reported for different fruits by Erenturk *et al.* (2005) and Al-Zubaidy and Khalil (2007). The fact that temperature and relative humidity of drying air have a considerable effect on the degradation of vitamin C in the dried product has been alluded to by various studies in the literature. (Hawlader *et al*., 2006; Ahmet *et al*., 2010; Dağhan, *et al*., 2018).

Table 1: **Proximate Composition of the Samples**

Sample	Moisture (%)	Protein (%)	Carbohydrate (%)	Ash (%)	Fat (%)	Fibre (%)
Plantain at 50 ℃	12.59±0.00^{h}	13.50±0.00^{h}	63.76±0.00^{e}	8.32±0.00^{i}	1.83±0.00^{i}	9.27±0.00^{i}
Hybrid at 50 ℃	11.84±0.00^{g}	13.31±0.00^{g}	65.71±0.00^{f}	7.56±0.00^{g}	1.58±0.00^{g}	7.92±0.00^{g}
Banana at 50 ℃	12.84±0.00^{i}	14.88±0.00^{i}	62.94±0.00^{d}	7.98±0.00^{h}	1.72±0.00^{h}	8.65±0.00^{h}
Plantain at 60 ℃	10.08±0.00^{e}	12.31±0.00^{f}	69 .69±0.00^{g}	6.54±0.00^{f}	1.38±0.00^{f}	7.10±0.00^{d}
Hybrid at 60 ℃	9.96±0.00^{d}	11.50±0.00^{d}	71.13±0.00^{i}	6.16±0.00^{d}	1.25±0.00^{d}	7.22±0.00^{f}
Banana at 60 ℃	10.13±0.00^{f}	12.00±0.00^{e}	70.22±0.00^{h}	6.29±0.00^{e}	1.36±0.00^{e}	7.18±0.00^{e}
Plantain at 70 ℃	8.44±0.00^{c}	10.88±0.00^{c}	74.57±0.00^{j}	5.07±0.00^{c}	1.04±0.00^{b}	6.29±0.00^{c}
Hybrid at 70 ℃	7.98±0.00^{a}	10.06±0.00^{b}	75.99±0.00^{k}	4.96±0.00^{a}	1.01±0.00^{a}	5.88±0.00^{a}
Banana at 70 ℃	8.05±0.00^{b}	9.63±0.00^{a}	76.23±0.00^{l}	5.03±0.00^{b}	1.06±0.00^{c}	6.17±0.00^{b}
Plantain at sun	14.78±0.00^{l}	17.94±0.00^{l}	55.39±0.00^{a}	9.84±0.00^{k}	2.05±0.00^{k}	11.24±0.00^{k}
Hybrid at sun	13.59±0.00^{j}	16.44±0.00^{j}	59.22±0.00^{c}	8.77±0.00^{j}	1.98±0.00^{j}	10.87±0.00^{j}
Banana at sun	14.68±0.00^{k}	17.44±0.00^{k}	55.91±0.00^{b}	9.86±0.00^{l}	2.11±0.00^{l}	11.26±0.00^{l}

It also showed that the degradation of vitamin C value changes with the equilibrium moisture content of the product after drying. Since increasing drying air temperature decreases the equilibrium moisture content of the product, the greatest loss in degradation of vitamin C and β-carotene occurs at the highest value of the temperature considered. It was observed that the vitamin C and β-carotene content of the banana after drying was more than the hybrid and plantain at both temperatures, as shown in Table 2. However, there is a general decrease in the vitamin C and β-carotene contents that were observed in the entire dried samples and at different temperatures of 50 and 60 ℃.

CONCLUSION

Energy and exergy analyses of the thin layer drying of plantain slices were accomplished in this study and based on the overall energy and exergy analysis, the result showed that drying at 50 and 60 ℃ for plantain (*False horn*) samples was more economical than at 70 ℃, which was the fastest but most unfavorable. Consequently, plantain (*False horn*) was the most suitable of the three sample conditions as it dried faster than its other varieties, while drying at 60 ℃ is the most acceptable based on its exergy efficiency, exergy loss, and evaporation heat, which

were moderate. The degradation of vitamin C and β-carotene in dried plantain samples increases with an increase in drying air temperature. The carbohydrate content of the samples increased while protein, fat decreased with an increase in temperature.

Table 2: Effect of Drying Time on the Composition of Vitamins A and C at 50 and 60 ℃

		50 ℃		60 ℃	
Sample	Time (h)	β-carotene (mg/kg)	Vitamin C (mg/kg)	β-carotene (mg/kg)	Vitamin C (mg/kg)
Plantain	2	0.037	9.304	0.031	8.106
	4	0.025	7.241	0.020	6.239
	6	0.011	5.832	0.009	4.258
	8	0.007	4.271	0.005	3.503
	10	0.005	3.628	0.004	2.825
	12	0.002	2.984	0.003	2.146
Hybrid	2	0.029	8.439	0.025	7.221
	4	0.021	7.218	0.025	7.221
	6	0.009	5.130	0.007	4.741
	8	0.005	3.982	0.004	2.985
	10	0.004	3.543	0.003	2.681
	12	0.004	3.104	0.001	2.377
Banana	2	0.042	9.625	0.038	8.249
	4	0.033	9.104	0.029	7.958
	6	0.027	7.732	0.018	6.243
	8	0.020	5.521	0.012	4.751
	10	0.017	4.450	0.011	3.890
	12	0.014	3.378	0.009	3.028

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