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Evaluation of Drying Behaviour of Cassava Chips under Open Sun and Oven Drying Technologies

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ABSTRACT

This study investigated the effect of drying temperatures and time on the drying rates, moisture content, and cyanide contents of five different species of cassava chips using two different drying technologies (oven and sun-drying). Fresh cassava tubers were chipped to uniform sizes of about 5×2×1 cm and dried using the two drying methods. The proximate analysis of the five different species was carried out both before and after drying. The final moisture contents of samples A–E are within the range of 12.05-14.81% for oven drying and 12.42-14.81% for sun drying, with sample D maintaining the highest moisture contents in both drying technologies. The results equally showed that the drying rates for samples A–E are within the range of 0.15-0.20 g/min for oven drying, and 0.022-0.025 g/min for sun drying, with sample E maintaining the lowest drying rates in both drying technologies. Oven drying produced a higher drying rate than sun drying. However, the cyanide retention for samples A–E is within the range of 0.00930-0.05339 mg/g for oven drying, with sample D maintaining the highest cyanide retention, while it is 0.00728-0.01589 mg/g for sun drying, with sample E maintaining the lowest cyanide retention. The cyanide retention obtained in oven and sun drying could be compared favorably to the standard value, with slight discrepancies that could be attributed to the initial cyanide content of the species and the drying temperatures. The results also show that cyanide content elimination is more effective in sun-drying than oven-drying because the drying temperatures remained below 55℃, which is optimal for cyanogen degradation. On the effect of time, the results remained constant; hence, it was only a function of the drying temperatures.

1. INTRODUCTION

The tuberous starchy root crop cassava (Manihot Esculenta, Crantz) belongs to the Euphorbiaceae family [1]. One of Nigeria's most significant root crops is cassava, accounting for about 45% of Nigeria's agricultural GDP. According to FAO statistics, over 250 million tons of cassava are cultivated annually in Nigeria and this represents billions of dollars in terms of revenue if properly processed and traded. Ikuemonisan et al. [2] observed that apart from Nigeria, numerous countries likewise depend on the end products of cassava. Most of the populations in these regions such as Africa, Asia, and Latin America depend on cassava for their daily livelihood sustainability [3]. In the initial stage of cassava processing, either grating the cassava into a mash or cutting the cassava root into chips are considered, however, both methods still retain high moisture and cyanide contents. Therefore, requiring drying at some stage for sustaining the shelf life of the product and also reduces the chemical content contained in it. Dried cassava also referred to as cassava chip is one of the most suitable means of preparing a cassava root for exporting by the major cultivators of cassava in the world such as Nigeria, Ghana, Tanzania, Philippines, etc. cassava chips are irregular slices of cassava tubes not longer than 5cm in length [4], it offers the direct conversion of cassava into powder form such as flour for baking, can also be processed into swallow foods like Amala in Nigeria. But that's only achievable if the cassava chip is properly dried, thus the need to explore more suitable and fast drying techniques.

The steps involved in producing cassava chips are simple and begin with peeling, washing then slicing the cassava roots into chips, next is the need to dry the chips for long-time preservation before being converted into the end product of choice [5]. To dry the chips, the traditional method (sun drying) or mechanized method (oven drying) can be considered. For sun drying, the chips are spread on concrete or trays in thin layers. Sun drying method has been reported to be inconsistent as it is weather dependent and requires a long drying time varying from 2-6 days while the practice is prone to insects and pest attacks due to its exposure to the atmosphere [6]. Another deficiency involved in the practice of sun drying is its low drying efficiency which can be attributed

to sun ray reflection by the surface of the white chips (5). The alternative drying method, the oven method has been explored in recent times with aim of tackling the limitations of the traditional methods. To aid in the understanding of the drying process, numerous research has focused on the drying behavior of cassava chips of various shapes in a controlled environment (oven) [7].

Research on cassava drying has often resulted from the keen interest in improving cassava processing in the production of dried chips on large scales [8]. Several studies have reported on different aspects of the drying behavior of the roots which include; moisture content, drying rates, cyanide content, and moisture ratio curves of cassava [9-13]. Mujaffar and Lalla [14] investigated the drying behavior of cassava chips via natural convection (<0.5 m/s) at a drying temperature of 60℃. Two chip sizes (3×2×1cm and 0.8×0.6×0.4 cm) were considered and dried until a constant weight was attained. In this work, the rate of decline in moisture content was observed to be influenced by the chip sizes. In addition, it took 18hr for the larger chips and 14hr for the smaller chips to attain equilibrium moisture. Also, an acceptable level of cyanide content was reported. Lastly, this study recommended a cassava chip size of 0.8×0.6×0.4 cm to ensure a rapid drying rate. Pornpraipech et al. [15] considered the effect of shape and temperature on the drying performance of cassava chips. The shapes considered are circular and rectangular while varying temperature ranging from 60-120℃ was proposed. The results showed that rectangular chips were suitable at optimal Parameters of 100℃, while less drying time was obtained compared to circular chips. Lastly, the experimental data were subjected to statistical analysis to study the drying behavior. Okonkwo et al. [16] investigated the influence of temperature on the drying rate and cyanide content of cassava chips. The oven drying method was considered in this study on the drying of five varieties of cassava and a suitable cyanide level was obtained for all the cassava varieties after the drying process. Furthermore, this study agreed that an increase in temperature resulted in a higher drying rate of the chips. Lastly, the drying temperature was observed to influence the cassava chip's drying rates, moisture, and cyanide contents.

The work aims to investigate and compare the behavior of critical parameters on cassava chip drying using both sun and oven methods. Furthermore, this study includes a presentation of drying moisture, drying rate, and cyanide content on five different cassava varieties to characterize the drying efficiency of the two methods under review.

2. MATERIALS AND METHODS

2.1 Material preparation

Five different varieties of fresh cassava roots as listed in Table 1 were sourced from local farms in Enugu, Nigeria. In the experimental investigation, 2kg of each cassava species were manually washed and peeled then chipped to the rectangular shape of 5 cm by 3 cm by 0.2 cm. To assess weight loss, moisture content, moisture percentage, drying rate, and cyanide concentration, the chips were sorted into equal sizes before being dried at a given temperature and drying period, chilled in a desiccator, and then reweighed.

Irrespective of the defaced surfaces of the cassava chips or areas that might have been chopped off as a result of human error, in each experiment, 2kg of each sample of the cassava chips was used to run it.

Table 1 and Figure 1 show the naming and samples of the prepared cassava chips.

Table 1. Categorization of the cassava varieties sourced

Sample	Cassava Variety Used
A	TMS
B	TME
C	TMS 97/2205
D	NR 87184
E	TMS 96/163

Figure 1. Samples used in the experiment

2.2 Experimental design

A 3-factor multilevel factorial design was utilized in this research to generate an experimental design matrix due to the different number of levels associated with the factors. The input parameters were cassava species at 5 levels, temperature, and time each at 3 levels of experimental runs.

2.3 Drying equipment

- **Reagents and Chemicals:**

The reagents used include; Sulphuric Acid (H_2SO_4), Boric Acid, HCl, N–Hexane, Picric Acid, Potassium Cyanide, and Sodium Hydroxide (NaOH),

- **Equipment:**

The drying equipment and accessories include; Electric Oven (DHG-9101-1SA GALLENKOMP, England), Hygrometer, Thermometer, Stopwatch, Digital Scale (Pioneer/Ohaus NO: PA213, China), Kjeldahl Flask, Anemometer, Conical Flasks, Beakers, Atomic Absorption Spectrophotometer (Buck Scientific 210 VGP), Desiccators, Muffle Furnace (Carbolite CWF 1200), Platinum Crucible, Filter Papers, Wire Gauze, Soxhlet Apparatus, Ram Bottom Flasks.

2.4 Drying procedures of the cassava chips

This research aims to investigate the drying efficiencies and the resulting behavior of the two drying methods namely open air (sun) and oven dryer on the cassava chips.

2.4.1 Sun drying process

The samples of the Cassava chips were spread on a neat concrete floor for 8 hours daily (from 10:00 am – 6:00 pm) as shown in Figure 2, for five days during which the cassava chips were turned over manually using a rake at varying intervals, depending on the intensity of the sun to obtain a uniform dried samples or to make the drying evenly spread on the sample thereby avoiding crumbs. As the samples lose their moisture contents when subjected to sun-drying, it shrinks in shape, thereby changing in shapes, breaking off, and defacing, but the same quantity by weight was not tempered irrespective of the areas that were chopped off. Then the loss in weight, moisture content (%), drying rate, and cyanide content was determined. Figure 2 is a Sample of the Cassava Chips used to describe the sun-drying processes. It followed the same methods and material preparations. Vital points to know in sun drying: 1. As the samples lose moisture contents upon drying (sun-drying) it shrinks in shapes thereby changing in shapes, breaking off, and defaced, but in all the same quantity by weight were not tempered irrespective of the areas that chopped off. The average weather conditions obtained are shown in Table 2.

Table 2. Average weather conditions of sun drying of the cassava samples

Days	Air Temperature T(℃)	Wind Speed (MPH)	Relative Humidity (RH)%	Time/day t(min)
1	30.3	9.76	66.0	480
2	31.0	10.00	65.5	480
3	29.5	8.50	68.5	480
4	30.4	9.81	66.1	480
5	31.3	10.05	65.5	480

Figure 2. Sun drying of the samples

2.4.2 Oven drying process

Drying was carried out in an Electric Oven (DHG-9101-1SA GALLENKOMP, England). The initial weight (g) of the cassava chips varieties labeled as samples A – B were measured and recorded using Digital Scale (Pioneer/Ohaus NO: PA213, China). Also, the samples were transferred to a wire mesh tray during the drying period in the oven. Thus, Table 3 and Table 4 present the parameters' calculation using two different methods: the variable temperature at a constant time and varying time at a constant temperature.

2.5 Drying analysis, moisture content calculation

The drying behavior of the cassava chips using the sun and oven was analyzed by taking into consideration the following in percentage; MC, crude fat, crude fiber, protein content, ash matter, and cyanide content (mg/kg).

Using the weight loss basis standard, the moisture content (MC) of the five samples was carried out. 5g was measured from each sample via the Digital Scale (Pioneer/Ohaus NO: PA213, China) in an air oven at 100℃ for 6hrs and the weight difference was recorded as MC and expressed in percentage (MC%). Moisture content was obtained using Eq. (1) according to Nirmaan et al. [17].

$$MC = \frac{W_i - W_f}{W_i} \tag{1}$$

where, MC is Moisture content, W_i is Initial sample mass, W_f is the Final mass after drying.

This represents the weight changes during the drying process using both drying methods. Using the digital balance, the initial mass of the sample was measured and recorded (Wet basis) before drying, then the final mass was obtained at the point where there was no change in the sample's mass or negligible weight difference (dry basis). Eqns. (2) and (3) represent the moisture content in (%). Drying rate curves were constructed, while comparisons were drawn to show various relationships between each drying parameter.

$$MC_{wb} = \frac{W_{tw} - W_{tdm}}{W_{tw}} \times 100 \tag{2}$$

$$MC_{d,b} = \frac{W_{tw} - W_{tdm}}{W_{tw}} \times 100 \tag{3}$$

where, MC_{wb} is % wet basis Moisture content, MC_{db} is % dry basis Moisture content, W_{tw} and W_{tdm} represent the initial wet weight and dry matter Weight respectively.

2.6 Dry matter and protein content

Dry matter content was calculated using Eq. (4):

$$100 - MC \tag{4}$$

where, MC is Moisture content (mc).

Kjeldahl method was considered for the samples' total protein content. A Kjeldahl flask was filled with around 0.2g of the ground samples, 10 ml of concentrated sulfuric acid, and one Kjeltec tablet to create a clear solution. 50 ml of a 40% NaCl solution was then added to the mixture, followed by 75 ml of distilled water. After the combination formed ammonia, it was steam distilled into a 25 ml solution of 2% boric acid that contained 0.5 ml of an indicator. After that, 0.1 N HCl was titrated with the collected distillate. The reagent underwent a blank titration, and the amount of nitrogen in the sample was determined. The crude protein content was calculated by multiplying the nitrogen concentration by 6.25.

2.7 Crude fat and ash content, crude fibre, carbohydrate, and cyanide content

Using a soxhlet device, the method for calculating crude fat was used. In a thimble, 3g of the powdered material was placed, and after 6 hours, n-hexane was extracted [18]. Evaporation was used to get the solvent out of the extracted

oil. To get rid of any remaining organic solvent and moisture, the oil was further heated at 100℃ for 30 min in a hot-air oven. The flask containing the extracted oil was weighed after being cooled in desiccators. The amount of oil collected was represented as a percentage of the weight of the original sample. Using a muffle furnace (Gallenkamp, England), the official method was used to measure the amount of ash [19]. Two grams of the sample were weighed into known-weight platinum crucibles, which were then heated to 600℃ in the muffle furnace chambers until they turned to ashes. The crucibles were taken out, allowed to cool in a desiccant, then weighed. Ash content was calculated as a % of the original sample weight.

Table 3. Formulas for calculating drying rate at constant time

T (℃)	WS (g)	WL (g)	MC (g)	MC (%)	DR (g/min)	CC (mg/g)	t (min)
30	WS_O	–	$WS_O - WS_7$	$\left({}^{MC_O}/_{WS_O}\right) \times 100$	–	$(CC)_O$	0
40	WS_1	$WS_O - WS_1$	$MC_O - WL_1$	$\left({}^{MC_1}/_{WS_1}\right) \times 100$	$\frac{WL_1}{t}$	$(CC)_1$	70
50	WS_2	$WS_O - WS_2$	$MC_O - WL_2$	$\left({}^{MC_2}/_{WS_2}\right) \times 100$	$\frac{WL_2}{t}$	$(CC)_2$	70
60	WS_3	$WS_O - WS_3$	$MC_O - WL_3$	$\left({}^{MC_3}/_{WS_3}\right) \times 100$	$\frac{WL_3}{t}$	$(CC)_3$	70
70	WS_4	$WS_O - WS_4$	$MC_O - WL_4$	$\left({}^{MC_4}/_{WS_4}\right) \times 100$	$\frac{WL_4}{t}$	$(CC)_4$	70
80	WS_5	$WS_O - WS_5$	$MC_O - WL_5$	$\left({}^{MC_5}/_{WS_5}\right) \times 100$	$\frac{WL_5}{t}$	$(CC)_5$	70
90	WS_6	$WS_O - WS_6$	$MC_O - WL_6$	$\left({}^{MC_6}/_{WS_6}\right) \times 100$	$\frac{WL_6}{t}$	$(CC)_6$	70
100	WS_7	$S_O - WS_7$	$MC_O - WL_7$	$\left({}^{MC_7}/_{WS_7}\right) \times 100$	$\frac{WL_7}{t}$	$(CC)_7$	70

Table 4. Formulas for calculating drying rate at constant temperature

t (min)	WS (g)	WL (g)	MC(g)	MC (%)	DR (g/min)	CC (mg/g)	T (℃)
t_0	S_O	–	$S_O - WS_7$	$\left({}^{MC_O}/_{WS_O}\right) \times 100$	–	$(CC)_O$	30
t_1	WS_1	$WS_O - WS_1$	$MC_O - WL_1$	$\left({}^{MC_1}/_{WS_1}\right) \times 100$	$\frac{WL_1}{t_1 - t_0}$	$(CC)_1$	100
t_2	WS_2	$WS_O - WS_2$	$MC_O - WL_2$	$\left({}^{MC_2}/_{WS_2}\right) \times 100$	$\frac{WL_2}{t_2 - t_0}$	$(CC)_2$	100
t_3	WS_3	$WS_O - WS_3$	$MC_O - WL_3$	$\left({}^{MC_3}/_{WS_3}\right) \times 100$	$\frac{WL_3}{t_3 - t_0}$	$(CC)_3$	100
t_4	WS_4	$WS_O - WS_4$	$MC_O - WL_4$	$\left({}^{MC_4}/_{WS_4}\right) \times 100$	$\frac{WL_4}{t_4 - t_0}$	$(CC)_4$	100
t_5	WS_5	$WS_O - WS_5$	$MC_O - WL_5$	$\left({}^{MC_5}/_{WS_5}\right) \times 100$	$\frac{WL_5}{t_5 - t_0}$	$(CC)_5$	100
t_6	WS_6	$WS_O - WS_6$	$MC_O - WL_6$	$\left({}^{MC_6}/_{WS_6}\right) \times 100$	$\frac{WL_6}{t_6 - t_0}$	$(CC)_6$	100
t_7	WS_7	$WS_O - WS_7$	$MC_O - WL_7$	$\left({}^{MC_7}/_{WS_7}\right) \times 100$	$\frac{WL_7}{t_7 - t_0}$	$(CC)_7$	100

NB. WS =Initial Sample Weight; WL = Weight Loss of the Sample; MC = Moisture Content; DR = Drying Rate; CC = Cyanide Content; t = Drying Time; T = Temp

Using 2g of a ground sample that was extracted with n-hexane, crude fiber was calculated as per the instructions This was then put into a 1-liter flask. Sulphuric acid with a boiling point of 1.25% (v/v) was added to the flask, which was then placed on a hot plate and allowed to boil for 30 minutes. Filtering the material was followed by washing the residue with 50 to 70 ml of distilled water. After removing the residue, 200 ml of boiling 1.25 (w/v) NaOH was added, and it was then allowed to boil for 30 minutes. Filtered water was used to wash away the leftover material. After being moved to an ashing dish, the residue was dried at 130°C for two hours before being chilled in a desiccator and weighed. Then this was set on fire. This was then ignited at 600°C, cooled, and reweighed. The weight difference represents the crude fiber. Eq. (5) is used to determine the amount of carbohydrates by subtracting the sum of the amount of moisture, ash, fat, protein, and crude fiber from the total 100%.

$$100\%\ Carbohydrate = 100 - (\%\ MC + \%ash + \%protein + \%fat + \%fibre) \quad (5)$$

The evaluation of the cyanide contained in both fresh and dried cassava chip samples was carried out using the colorimetric Alkaline Picrate method reported by the work of Ekere and Eze [20]; Njoku and Mbah [21]. A yellowish alkaline picrate solution consisting of dissolved 5g Na_2CO_3 and 1g picric acid in distilled water was obtained. Then, about 4.0 ml of the alkaline solution and 1.0 ml of liquid extract from the cyanide extraction process were measured into a test tube and corked. The incubation of the mixture at 50℃ lasted for 5 min which will aid colour transformation (yellowish colour to reddish colour). The absorbance was then measured using a UV/visible spectrophotometer at 490 nm wavelength (Jenway 6405, England). The standard curve that was utilized to determine the cyanide level of the experimental samples was

prepared using diluted potassium cyanide (KCN).

3. RESULTS AND DISCUSSION

3.1 Drying performance

Five special species of cassava roots namely; TMS 96/1632, TMS 98/0510, TMS 97/2205, NR 87184, and TME 419 were considered in this study in understudying the drying performance of both oven and sun drying methods. The effects of the two drying methods on the cassava chips were observed and the proximate analysis of the chips was considered. The results are presented in Table 5.

3.2 Relationship between drying rate, cyanide, and moisture contents of the samples at a constant time in oven drying

(a) Cyanide versus Moisture Contents

There is a relationship between the cyanide and moisture contents. This relationship can be seen in Figure 3. Observation from the shapes of the graphs shows that the relationship between the cyanide and moisture contents at a constant time is the same for the five samples. From the graphs, the chips exhibited sharp falling rate gradients from the maximum to minimum level, which is a clear indication that the moisture and cyanide contents were affected by the temperatures.

(b) Cyanide Content versus Drying Rate

There is a relationship between the cyanide content and drying rate. This relationship can be seen in Figure 4. Observations from the shapes of the graphs show that the relationship between cyanide content and drying rate at a constant time is almost the same for the five samples. The chips exhibited sharp falling rate gradients, which is a clear indication that the drying rate and cyanide contents were affected by the temperatures. Also, the temperature variation led to a decrease in moisture content as cyanide contents were reduced.

Table 5. The experimental results obtained

StdOrder	RunOrder	PtType	Blocks	Species	Temperature (°C)	Time (min)	Drying rate	Moisture contents
3	1	2	1	A	65	60	0	0.96
7	2	1	1	D	30	60	0.01	0.86
14	3	0	1	C	65	35	0.03	0.77
8	4	1	1	B	100	10	0.03	0.7
5	5	2	1	E	100	35	0.09	0.64
10	6	1	1	B	100	60	0	0.95
12	7	1	1	A	30	60	0.02	0.75
6	8	2	1	D	30	35	0.06	0.65
1	9	1	1	E	100	60	0.08	0.74
2	10	1	1	C	30	10	0.15	0.6
11	11	1	1	A	100	10	0	0.8
9	12	1	1	E	30	10	0.05	0.57
13	13	0	1	A	65	35	0.07	0.48
4	14	2	1	B	65	10	0.11	0.38

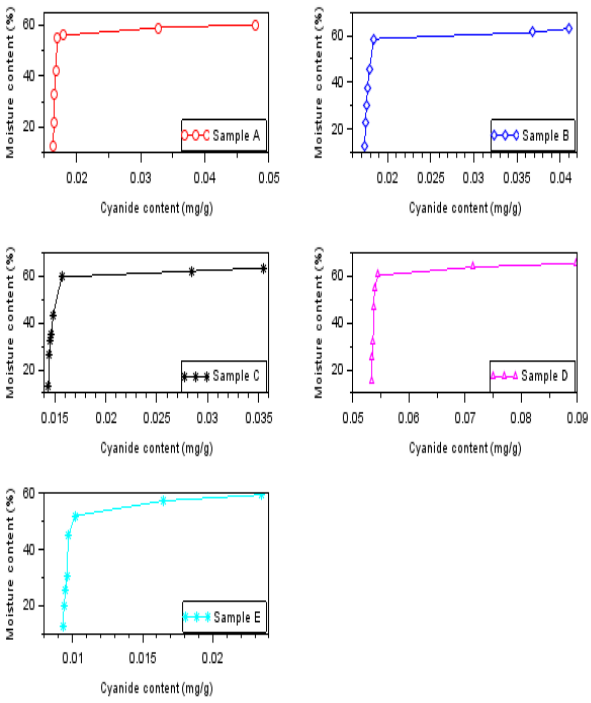

Figure 3. Moisture versus cyanide contents of the samples at a constant time in oven drying

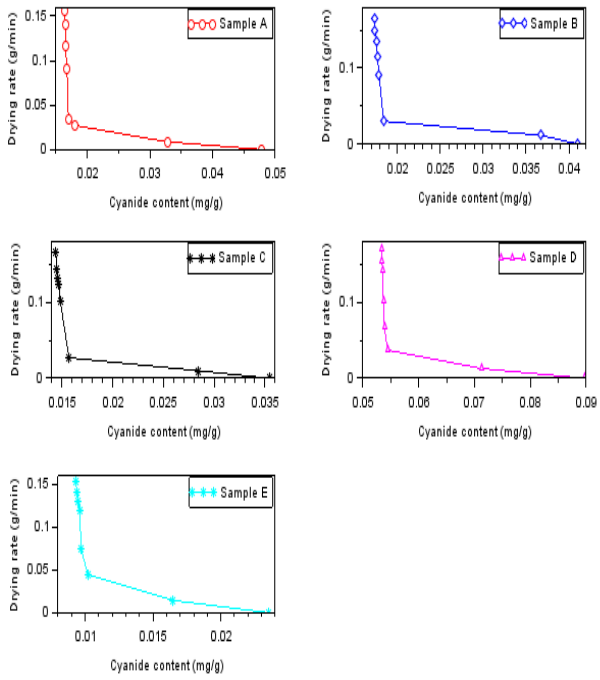

Figure 4. Cyanide content versus drying rate of the samples at a constant time in oven drying

(c) Drying Rate versus Moisture Content

There is also a relationship between the drying rate and moisture content. This relationship can be seen in Figure 5. Observation from the shapes of the graphs equally shows that the relationship between the drying rate and moisture content at a constant time is the same for the five samples. However, this observation is equally an indication that the drying rate and moisture content were affected by the temperatures.

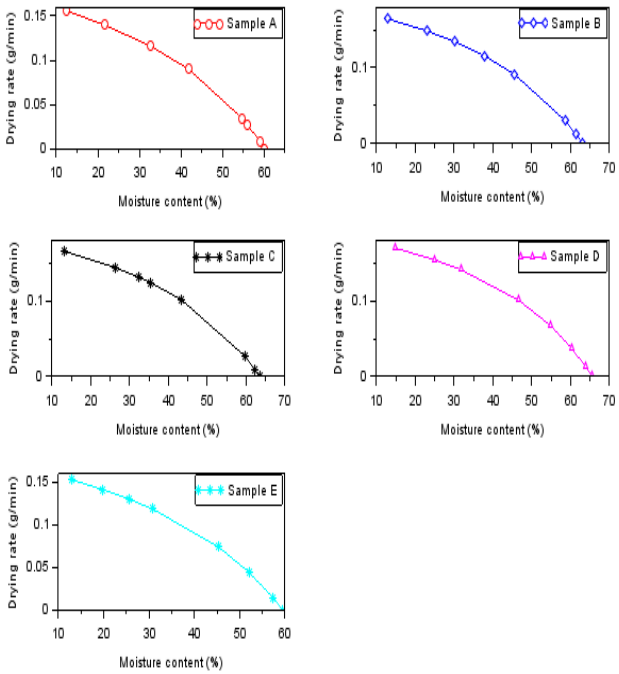

Figure 5. Drying rate versus moisture content of the samples at a constant time in oven drying

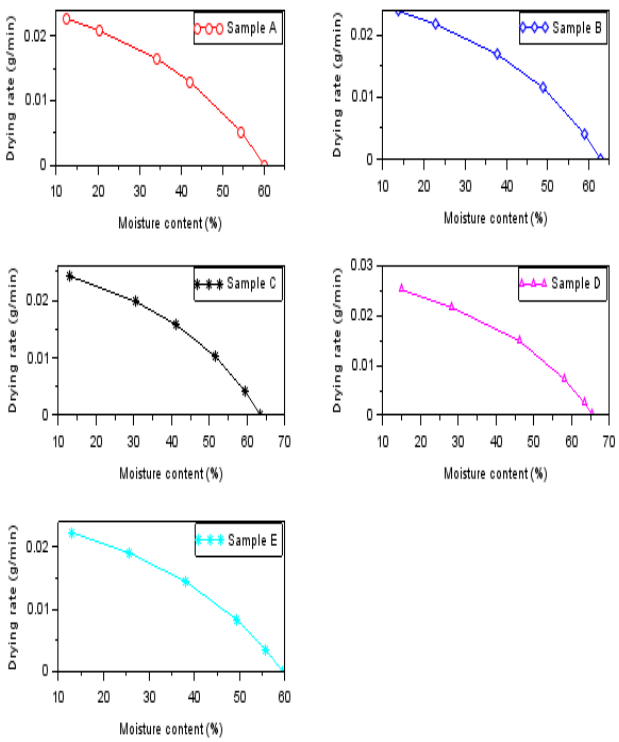

Figure 6. Drying rate versus moisture content of the samples in sun drying

3.3 Relationship between drying rate, moisture, and cyanide contents of the samples in sun drying

(a) Drying Rate versus Moisture Content of the Samples

Figure 6 shows the relationship between drying rate and moisture content under sun drying. Observations from the shapes of the graphs show that the fine samples share a similar trend. However, this observation is a clear indication that sun drying influenced the rate of drying as well as moisture content.

(b) Relationship between Moisture and Cyanide Contents of the Samples

There is a relationship between moisture and cyanide contents in sun drying. This relationship can be seen in Figure 7. Observations from the shapes of the graphs show that the relationship between the moisture and cyanide contents of the five samples was not the same. The shapes of samples A, B, and C were almost the same with slightly different. While the shapes of samples D and E were different from each other. Although the moisture and cyanide contents of the samples were affected by the duration of drying in sun drying.

(c) Relationship between Cyanide Content and Drying Rate of the Samples

There is a relationship between the drying rate and cyanide contents in sun drying. This relationship can be seen in Figure 8. Observations from the shapes of the graphs show that the relationship between the drying rate and cyanide contents of the five samples was not the same. The shapes of samples A and B were almost the same with slightly different. While the shapes of samples C, D, and E were also different from one another. Although the drying rate and cyanide contents of the samples were affected by the duration of drying in sun drying.

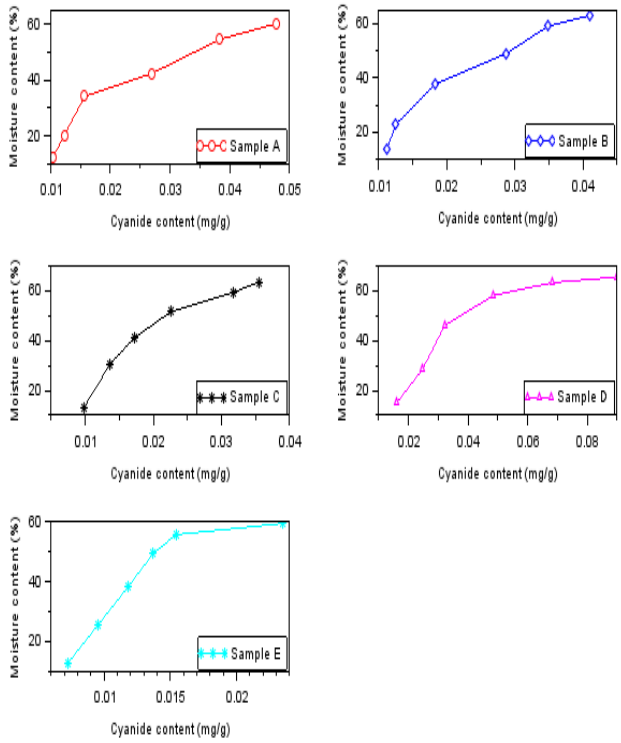

Figure 7. Cyanide versus moisture contents of the samples in sun drying

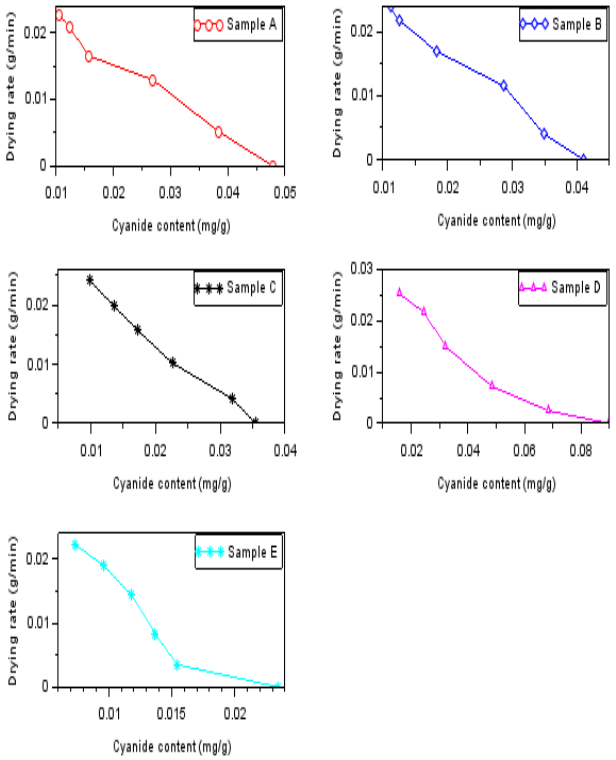

Figure 8. Cyanide content versus drying rate of the samples in sun drying

3.4 Proximate analysis of the cassava chips before and after drying

Tables 6-8 present the proximate analysis of the cassava chips before drying and after drying in both sun and oven methods.

3.4.1 Comparative analysis of oven and sun drying of the samples

- **Moisture Content**

From the experimental results, it was discovered that the rate of moisture reduction is faster in oven drying than in sun drying reasons because of higher temperature difference. Moreover, the results show increasing drying time resulted in a drastic drop in the moisture content of all five chip samples till it attained equilibrium. Furthermore, the results also showed that an increase in the duration of drying in the sun-drying process equally brought about a corresponding decrease in the moisture content. However, the most significant effect in this analysis is that oven drying is faster, and requires less time and effort to reduce the initial moisture contents of the cassava chips (60.15%, 62.95%, 63.50%, 65.50%, and 59.50%) to the final moisture contents of (12.42%, 12.94%, 13.10%, 14.81%, 12.90% and 13.04% 13.84%, 12.05%, 13.75%, and 13.83%) respectively, which is in strong agreement with moisture level ranging from 12 to 15%. While sun drying is slower, requires more effort, and took about five days to reduce the initial moisture contents of the cassava chips (60.15%, 62.95%, 63.50%, 65.50%, and 59.50%) to the final moisture contents of (12.42%, 13.84%, 13.10%, 14.81%, and 12.90%) respectively which is in accordance with MC. These significant effects of the analysis could be seen in Figure 3.

- **Drying Rate**

The results from the experiment showed that oven drying produced a better and higher drying rate than sun drying because of the high drying temperatures. Moreover, as the drying time increases, the drying rate of the cassava chips equally increases in oven drying than sun drying (0.16, 0.16, 0.16, 0.17,0.15 and 0.19, 0.20, 0.19, 0.20 and 0.20) g/min respectively. In other words, sun drying produced a lower drying rate (0.0227, 0.0238, 0.0242, 0.0252, and 0.0223) g/min respectively. However, this significant effect could be seen from the drying characteristics of the cassava chips in Figure 5.

- **Elimination of Cyanide Content**

In oven drying, cyanide retention in the cassava chips was solely a function of the temperature and was not influenced by the drying duration. Experimental results showed that sun drying is more effective in the elimination of cyanide content than oven drying. Moreover, better cyanide retention is achieved through sun drying than oven drying because the drying temperature remains well below 55°C. These temperatures are ideal for linamarase activity, resulting in better cyanogen degradation. These results are obtained from sun drying of the cassava chips (0.01040, 0.01121, 0.00980, 0.01589, and 0.00728) mg/g. Although the recommended standard for cyanide contents in dried cassava chips is 0.01000 mg/g (ARS 839: 2012). The discrepancies in the cyanide contents of samples D and E (0.01589 and 0.00728) mg/g respectively could be attributed to the maximum and minimum original cyanide contents of 0.089 mg/g and 0.024 mg/g respectively in the cassava chips. However, in oven drying, an increase in drying temperature is accompanied by an increase in cyanide retention (0.01634, 0.01739, 0.01439, and 0.05339) mg/g. More so, at drying temperatures above 55°C, linamarase activity is inhibited, and therefore, linamarin starts to accumulate in the dried cassava chips. This significant effect could be seen in Figures 7 and 8.

3.5 Effect of duration on drying of the samples in sun drying

3.5.1 Effect of duration on moisture content of the samples

One of the most crucial drying factors is drying time. Figure 9 shows the effects of time on the chips' moisture content. As the period was prolonged, it was observed that the moisture content fell uniformly across all samples. This demonstrates that when drying cassava chips, drying time must be taken into account. Another important deduction from the graph is that the initial moisture contents of the five samples were finally reduced to; 12.42%, 13.84%, 13.10%, 14.81%, and 12.90% respectively, this result is in good agreement with the work of Ge et al. [22] which recommended moisture content within the range 12 to 15%. This difference in the initial moisture contents could be attributed to the chemical compositions of the cultivars [23]. Furthermore, it is pertinent to note that the investigation was done under the average weather conditions in Table 2. But observations from Sekyere et al. [24] reported that it took about three to four days to dry cassava chips to a moisture content of 13%, depending on the weather conditions. In addition, the shapes of the graphs for the moisture contents for the five samples are almost the same. However, samples D and E had the maximum and minimum initial moisture contents of 65.50% and 59.50% respectively.

Table 6. Proximate composition of the fresh samples

Sample	Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	Carbohydrate (%)	Moisture Content (%)	Dry Matter (%)
A	1.43	0.27	3.95	2.0.04	11.89	60.15	39.85
B	1.08	0.25	3.14	1.55	12.58	62.95	37.05
C	1.80	0.30	4.25	1.89	13.34	63.50	36.50
D	2.35	0.38	5.23	2.84	15.87	65.50	34.50
E	1.32	0.23	3.65	1.44	11.09	59.50	40.50

Table 7. Proximate composition analysis for sun dried samples

Sample	Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	Carbohydrate (%)	Moisture Content (%)	Dry Matter (%)
A	3.11	1.14	7.98	3.04	5.89	12.42	87.58
B	4.08	1.21	9.45	3.28	5.58	12.94	87.06
C	4.45	1.28	11.25	4.11	7.34	13.10	86.90
D	4.75	1.33	12.23	5.23	8.87	14.81	85.19
E	3.89	1.19	9.14	2.98	6.09	12.90	87.10

Table 8. Proximate composition analysis for oven dried samples

Sample	Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	Carbohydrate (%)	Moisture Content (%)	Dry Matter (%)
A	3.11	1.14	7.98	3.04	5.89	12.42	87.58
B	4.08	1.21	9.45	3.28	5.58	12.94	87.06
C	4.45	1.28	11.25	4.11	7.34	13.10	86.90
D	4.75	1.33	12.23	5.23	8.87	14.81	85.19
E	3.89	1.19	9.14	2.98	6.09	12.90	87.10

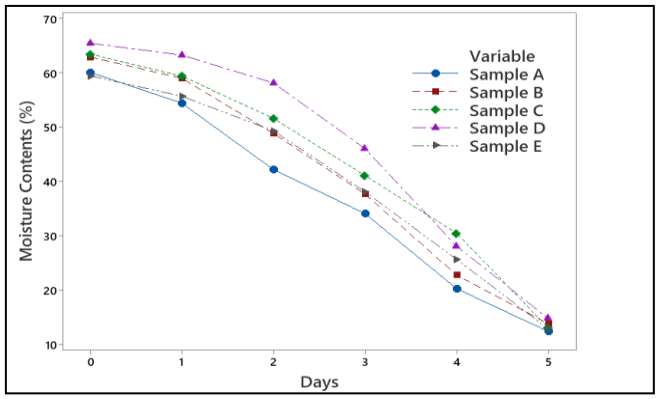

Figure 9. Effect of duration on moisture content of the samples in sun drying

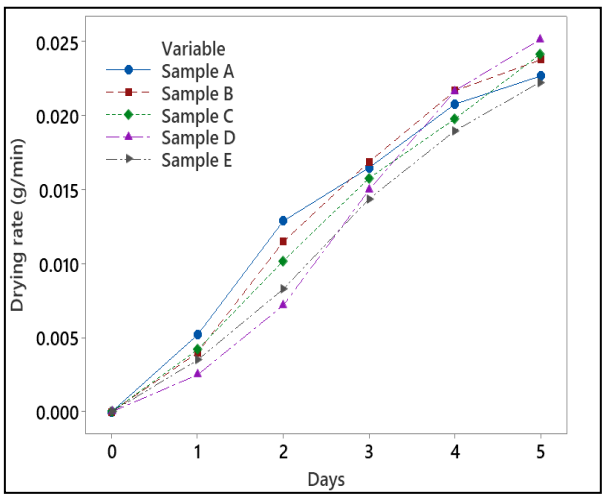

Figure 10. Effect of duration on drying rate of the samples in sun drying

3.5.2 Effect of duration on drying rate of the samples

Figure 10 illustrates how the drying period has an impact on the drying rate. The rate, at which the cassava chips dry, however, rises as drying time increases. Although, the rate was closely minimal compared to the oven drying method which could be attributed to the weather condition. With the similarities among the characteristics of the samples, Ndukwu et al. [25] attributed this to the differences in the chemical composition of the cultivars. Furthermore, only samples D and E recorded the maximum and minimum drying rates of 0.0252 g/min and 0.0223 g/min respectively.

3.5.3 Effect of duration on cyanide

The cassava chip's drying duration is a very important factor in the elimination of cyanide contents in sun drying. The effect of the duration of drying on the cyanide contents of chips in sun drying is shown in Figure 11. Observations from the results obtained show that the elimination of the cyanide level was greatly affected by the duration of drying of the cassava chips in the sun drying method. As the duration of drying increased, the cyanide contents of the samples also decreased steadily similar to the recommended standard of 0.01 *mg/g* [26], except samples D and E which had the final cyanide contents of (0.01589 mg/g and 0.00728 mg/g) respectively which were a little different from the recommended standard and could be attributed to the maximum (0.08980 mg/g) and minimum (0.02350 mg/g) cyanide contents the cultivars initially contained respectively. In addition, a close inspection of the graphs a similar trend in all the sample's cyanide contents except for sample D results which tends to be a little higher, reasons which could be aligned to the highest initial cyanide content (0.08980 mg/g). However, the effectiveness of sun drying in the elimination of cyanide compared to the oven drying method was reported by Chongtham et al. [27] as it allows more contact time between linamarase and cyanoglycosides and retains water, essential for linamarase action, for a longer time in the cassava tubers. Furthermore, Ayele et al. [28] observed that when temperatures are kept far below 55°C when drying in the sun, cyanide retention is lower than when drying in an oven. Because linamarase activity is best at these temperatures,

cyanogen is degraded more effectively. More linamarin is deglycosylated into cyanohydrin as a result of higher linamarase activity during sun-drying processes, which causes cyanohydrin and free cyanide to build up in the work of Bassey et al. [29]. Additionally, due to longer drying times, higher moisture contents, and temperatures at which endogenous linamarase is active, sun drying would result in greater losses of cyanide concentrations than oven drying in the report by Cappelli et al. [30].

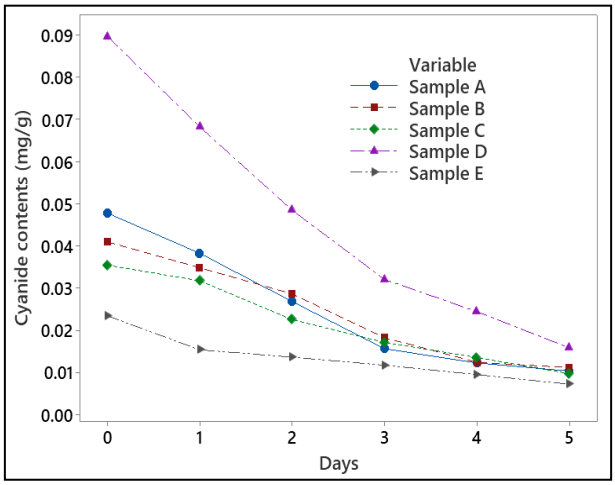

Figure 11. Effect of duration on cyanide content of the samples in sun drying

4. CONCLUSION

The post-harvest storage of fresh cassava roots is almost impossible due to some factors such as moisture and other toxic substances present in it (hydrocyanic acid). Thus, the demand for a critical evaluation of drying methods involved in cassava chips to ascertain the effects of each method on the physiochemical properties of the cassava chips which are liable for its preservation and the energy cost involved. 3-factor multi levels factorial design was utilized to generate an experimental design matrix showing the various factors e.g Factor A: Cassava species at 5 levels, factor B: temperature at 3 levels and factor C: time at 3 levels. The results showed that the drying characteristics of the chips in this study exhibited a falling rate primarily. More so, the temperature played a major role in the drying of cassava chips. However, temperatures and time had a significant impact on the drying rates, moisture, and cyanide level of the cassava chips samples.

i. Furthermore, the results from the oven drying process gave higher drying rates than the sun drying process.
ii. Samples D and E recorded the maximum and minimum drying rates of 0.0252 g/min and 0.0223 g/min respectively due to the chemical composition of the cultivars.
iii. On the other hand, the results from sun drying of the cassava chips showed that the process is more effective in the elimination of cyanide content than the oven drying process because the drying temperatures remained well below 55°C which is optimal for linamarase activity, resulting in better cyanogen degradation.
iv. In other words, more linamarin is deglycosylated into cyanohydrin during the sun-drying process, increasing linamarase activity.

Furthermore, the sun-drying process prolongs the time contact time between linamarase and cyanoglycosides in the aqueous media.

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