TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH

TURKAGER

e-ISSN: 2717-8420

https://dergipark.org.tr/en/pub/turkager

VOLUME : 3
ISSUE : 2
YEAR : 2022

Turkish Journal of Agricultural Engineering Research
(TURKAGER)
Volume 3,
Issue 2,
Year 2022

Indexing / Abstracting

Turkish Journal of Agricultural Engineering Research (TURKAGER)

PUBLISHER

Prof. Dr. Ebubekir ALTUNTAŞ */ Tokat Gaziosmanpaşa University, TÜRKİYE*

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Turkish Journal of Agricultural Engineering Research (TURKAGER)

ADVISORY BOARDS (*)

Turkish Journal of Agricultural Engineering Research (TURKAGER)

Volume 3,
Issue 2,
December 31, 2022

REFEREES (*)

(*): The list is based on the surname of the editors in alphabetical order.

Turkish Journal of Agricultural Engineering Research (TURKAGER)

Volume 3,
Issue 2,
December 31, 2022

Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1118633

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 204-213

Research Article

Usage of Special Feeder for Small Birds

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ABSTRACT

This study presents the possibility of using agricultural by-products to solve the problem of high forage prices. Rice mill pre-cleaning residues are considered solid waste in Egypt, as many tonnes are produced every day. These overgrown heaps always cause an environmental problem. Most millers don't know how to dispose of it. A simple device for the purification of it to use as a supplementary feeder for small birds has been manufactured. It comprises an air supply, a hopper, a case, and two drawers (one for receiving eaten parts and the other for receiving impurities). The mixture of rice millers' residues is agitated by the air stream and floats the fine particles upwardly in the far drawer while the air escapes through the final air holes. Performance evaluation was conducted on the manufactured device with various airspeeds (1.8, 2.6, 3.2 and 4.3 m s^{-1}), baffle angles (30, 40, and 50°) and feed rates (3.6, 5.7, 8.2, and 9.3 kg min^{-1}). The maximum value of purifying efficiency (87.67%) is achieved at an airspeed of 4.3 m s^{-1}, a baffle angle of 30°, and a feed rate of 3.6 kg min^{-1}. The minimum mean of losses (0.4%) is achieved at an airspeed of 1.8 m s^{-1}, a baffle angle of 50°, and a feed rate of 3.6 kg min^{-1}. There is a significant increase in the purifying efficiency and a significant decrease in losses when using the purifying device, so it is recommended to use it for the purification of rice residues.

RESEARCH ARTICLE

Received: 19.05.2022
Accepted: 18.07.2022

Keywords:

- Rice mill,
- Pre-cleaning residues,
- Purifying,
- Special feeder,
- Small birds

To cite: Al-Rajhi MAI (2022). Usage of Special Feeder for Small Birds. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 204-213.* https://doi.org/10.46592/turkager.1118633

INTRODUCTION

Rice in Egypt is the main cereal crop during the sunner season. The annual cultivated area is about 600000 ha, producing 6 million tons of paddy rice. The average yield of 10 t ha^{-1} is considered as one of the highest levels wordwide (RRTC, 2018). Rice milling is an important step in the production of rice, as rice is a vital source of food for about

3 billion people every year (FAOSTAT, 2017). Pre-cleaning, hulling, and post-hulling are all steps in the rice milling process. A pre-cleaner used in rice mills usually contains an oscillating double screen bed. The first screen is a scalper that lets through the grain but retains straw. The second screen retains the grain, but lets through broken grains, weed seeds, and fine dust. Pre-cleaning residues [broken grains, weed seeds such as Branyard grass (*Echinochloa crus-galli*), some light particles and fine dirt] are considered solid waste in common Egyptian rice mill centers. These overgrown heaps of rice residues cause environmental problems if not handled and adequately removed. There is an urgent need to search for the best method of disposing of this residue in order to encourage a healthy environment for everyone. Despite the numerous rice miller residues generated every day and their long-term effects on the surrounding environment, no serious attempts have been made to dispose of them safely (Njoku and Mbah, 2012).

Byproducts of rice milling have been investigated within animal production systems, particularly poultry (Ebling *et al.*, 2015; and Rubinelli *et al.*, 2017). Branyard grass is one of the most harmful weeds in rice crops (Heap, 2014a). Small birds like pigeons and canaries prefer to eat it, so it is grown for fodder, grain, or birdseed (Barkworth *et al.*, 2003). Also, ducks have been observed to eat the seeds of Branyard grass (Kramer and Euliss 1986). It is tested as a forage (Mitich, 1990).

Gravity separators separate seeds according to their weight and size. Long seeds are separated from short ones by indented discs and cylinder separators. Velvet roll separators remove smooth seeds from rough seeds. Electronic separators sense a difference in the electrical properties of seeds. The better and more efficient way to separate seeds that present a different resistance to airflow is through pneumatic and aspirator separation (Emami *et al.*, 2007).

In the Northern Delta of Egypt, large quantities of rice mill pre-cleaning residues accumulate from the numerous rice mills located in the area. So, it is necessary to study the possibility of using rice mill residues as a supplementary feeder for small birds. The specific objectives of the present study are to test and evaluate the device manufactured by EL-Shabrawy and Al-Rajhi, 2020, which is used to remove husks from the food [Barnyard grass (*Echinochloa crus-galli*)] of bet birds (Parakeets and Canaries) in removing impurities (fine dirt, dust, and very small particulates that either intermix with or adhere to rice grains) and to effectively use weed seeds and broken rice grains as a feeder.

MATERIALS and METHODS

Material

This study was conducted in a rice-producing district located 31.23° N, 31.98° E at Al-Manzala, Dakahlia Governorate, Egypt, during the summer season of 2021. A rice milling plant in the indicated producing region provided rice mill residues from rice varieties (*Oryza sativa* L.); namely cvs; Giza 178 (8.17 mm length, 3.97 mm width, 2.47 mm thickness and 16.87 g mass of 1000 grains). Giza 178 is an Egyptian high-class and high grain yield type with excellent cooking qualities. The used samples of rice mill pre-cleaning residues that accumulated under the pre-cleaner were collected and manually packed in polyethylene bags and kept at 4±1°C for three weeks. Before the experiment began, the samples were taken out of the refrigerator and maintained at room temperature. The components of rice mill pre-cleaning residues were determined before purifiying operation such as: mass of broken grains, weed seeds and fine particles in one kg.

Principles of operation

The main working principle of the purifying device is that when air is blown from the side, heavier materials are collected at one place, while lighter materials are blasted away by the strong air. Mixture have varying characteristics, which require different airspeeds for achieving the best result of purifying, therefore adjustment of airspeed and proper feeding of mixture is essential.

Device description

Figure 1a and Figure 1 b illustrates the device manufactured by EL-Shabrawy and Al-Rajhi, 2020 and used for purifying rice mill pre-cleaning residues. The device was made using clear polycarbonate sheets, a material that is available locally at a cheap price and is characterised by its rigidity, durability and transparency. It consists of a rectangular transparent body with a maximum length of 350 mm and a maximum width of 270 mm. It is divided into two equal portions and provided with a hopper. A supply hopper is disposed above the inlet, and a sliding gate was used for controlling mixture flow. The hopper's dimensions were selected based on symmetry, and it was constructed as a trapezoidal shape. The volume of the hopper is 0.045 m^3, and the angle of the base to the vertical is about 45°. Hopper receives and conveys mixture to the purifying unit. Two blast fans work as an air source and created an airflow transverse to the path of the particle flow to remove the fine particulates from the main mixture, as illustrated in Figure 2. On opposite sides of the device, alternately arranged downwardly sloping baffles receive particle flow and direct it into a rotatable means that converts the linear momentum of the particle flow as it cascades down the baffles to angular momentum, fanning out the fine particulates into the airstream. Each successive baffle is longitudinally spaced from the previous baffle. The lower edge of each baffle remotely overlaps the top surface of the successive baffles, so the particulate material introduced into the particle flow channel must follow a circuitous route from the material inflow inlet to the material outflow outlet. Once the particle flows and passes through the inlet, it impacts and gravitationally moves down the uppermost baffle towards the lower edge. To release the air, there is a series of finely spaced air holes on the opposite side of its lower end to allow the current of air to pass through it. It has a vertically placed column with a particle flow channel through which an airstream is generated. Figure 2 illustrates the switch (dimmer) used for regulating the air blast. Both fans are connected to the adapter with suitable wiring. The mechanism of the device manufactured by EL-Shabrawy and Al-Rajhi, 2020 and used to purify rice mill pre-cleaning residues is shown in Figure 3. Shows schematic diagram of the device.

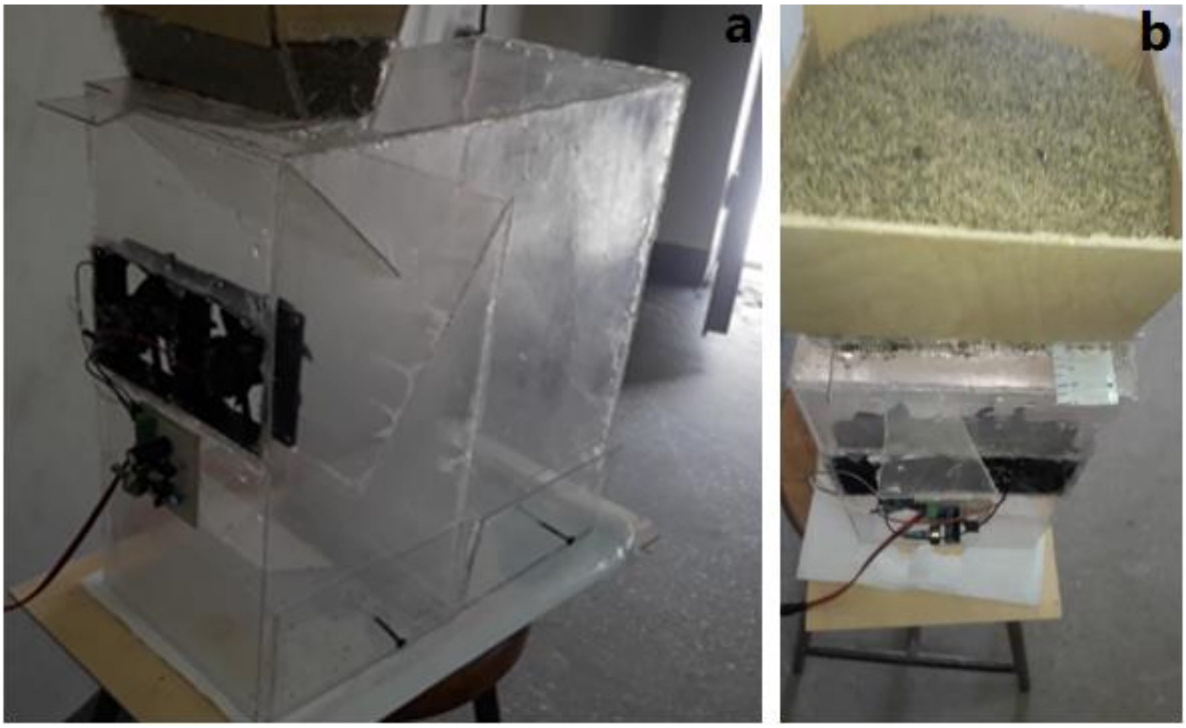

Figure 1. a. The device side view. **Figure 1. b.** The device rear top view.
Figure 1. The device of purifiying rice mill pre-cleaning residues.

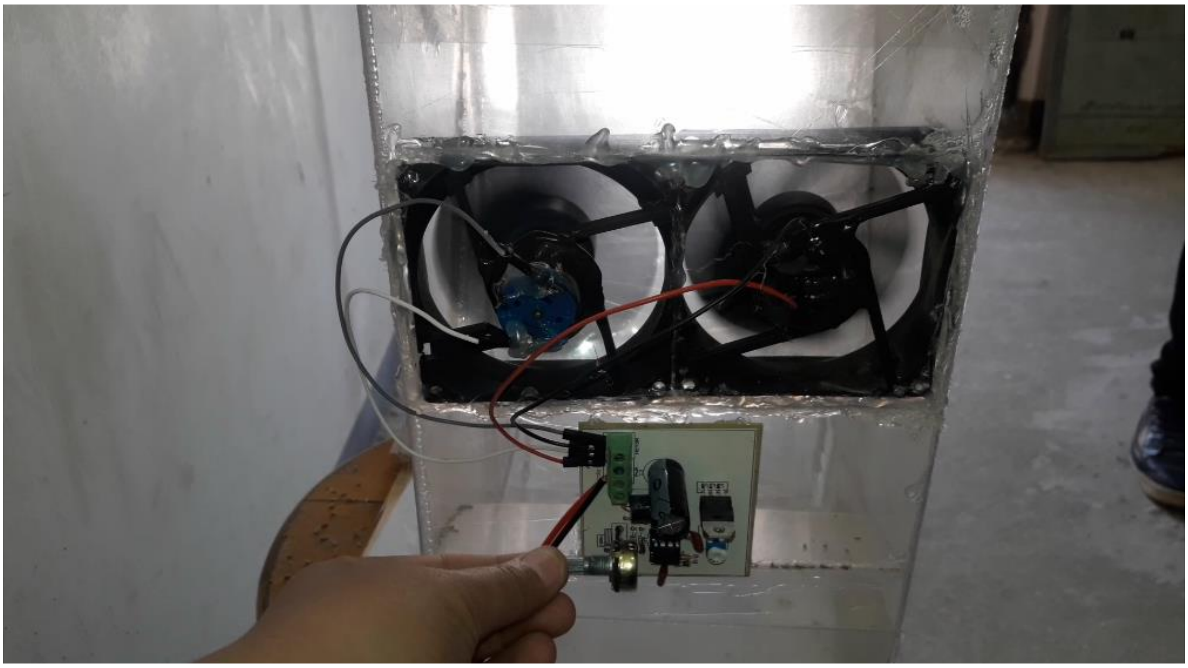

Figure 2: Blast fans and switch.

Methods
After a mixture of broken grains (1), weed seeds, fine dirt, dust, and very small particulates that either intermix with or adhere to rice grains is fed into the airflow path, the airflow removes the lighter material and allows the broken grains and weed seeds to fall into the first drawer (7). As shown in Figure 3, the material is subjected to a strong upward draft, which carries a significant portion of the lighter foreign matter into the air duct.

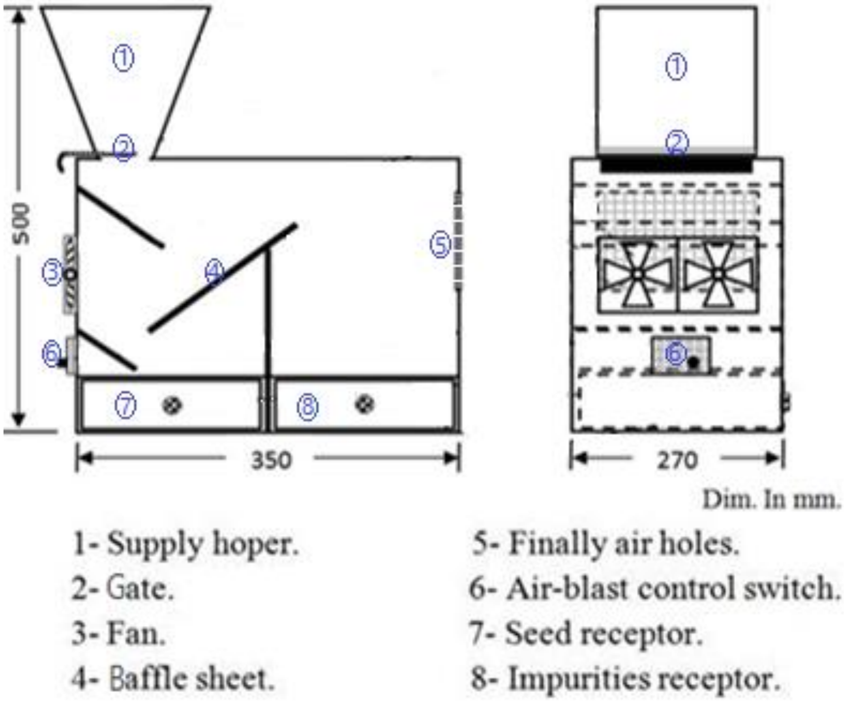

Figure 3. A schematic diagram of the device.

Experimental design and performance evaluation

The test's experimental design was a complete randomised. Anemometer was used to measure airspeeds in m s^{-1}. The baffle angle means the angle between the horizontal line and the line of the long baffle side. It was measured using a protractor. The feed rate test was timed using a stopwatch and the mass was measured using electric digital balance.

Tested variables

Three variables were studied. They were as follows:

1) Four airspeeds (*S*) of 1.8, 2.6, 3.2 and 4.3 m s^{-1} named S_1, S_2, S_3, and S_4 respectively, were adjusted using a dimmer located in the control panel (Figure 3).

2) Three baffle angles (*A*) of 30, 40 and 50° named A_1, A_2, and A_3 respectively, were investigated.

3) Four feed rates (*F*) of 3.6, 5.7, 8.2 and 9.3 kg min^{-1} were investigated, named F_1, F_2, F_3, and F_4 respectively.

Measurements

Feeding rate

The feed rate ($Fr.$, kg min^{-1}) was calculated using Equation 1.

$$Fr. = \frac{W_{\mathrm{mf}}}{T_t} \quad (1)$$

Where:

W_{mf} = Mass of mixture fed into hopper, kg

T_t = Total time taked, min.

Purifying efficiency, %

Purifying efficiency (ηp., %) was calculated using Equation 2.

$$\eta_{P.} = \frac{I_{sample} - I_{separated}}{I_{sample}} \times 100 \quad (2)$$

Where:

I_{sample} = Mass of impurities in the sample, g

$I_{\text{Separated}}$ = Mass of separated impurities, gram.

Losses, %

Losses (L, %) is calculated using Equation 3.

$$L = \frac{w_{sample} - w_{separated}}{w_{sample}} \times 100 \quad (3)$$

Where:

w_{sample} = Mass of the sample's eaten part, g

$w_{separated}$ = Mass of separated eaten part, gram.

Statistical analysis

The experiments were replicated three times. The data were statistically analyzed using the Costat Program (Oida, 1997) to determine the statistical significance of the variables under consideration based on the probability ($P<0.05$).

RESULTS AND DISCUSSION

Specification of rice mill pre-cleaning residues

Three samples of about 1 kg each were taken randomly from the abovementioned producing region. The components of the mixture were as indicated in the following Table 1. The eaten part represented 60.9% of the whole component.

Table 1. The components of rice mill pre-cleaning residues.

Mixture components of about 1000 gram		
Broken grains	Weed seeds	Fine particles
403 gram	206 gram	391 gram

Factors affecting purifying efficiency, %

The results are shown in Figure 4 illustrate the effect of airspeed, baffle angles, and feed rate on purifying efficiency, %. Increasing the cleaning speed increased the mean purifying efficiency from 72.67% at an airspeed of 1.8 m s^{-1} to 80.69% at an airspeed of 4.3 m s^{-1}. However, the mean best values for purifying efficiency were 81.02 and 80.59%, respectively, which were directly related to a baffle angle of 30° and feed rate of 3.6 kg min^{-1}. The mean minimum values for purifying efficiency were 72.88 and 74.33%, respectively, at a baffle angle of 50° and a feed rate of 9.3 kg min^{-1}. These results can be attributed to the low baffle angle, which scatters the mixture and exposes the most amount of mixture to the air stream, as well as the lower feed rate, which allows for a longer exposure period to the cleaning air stream.

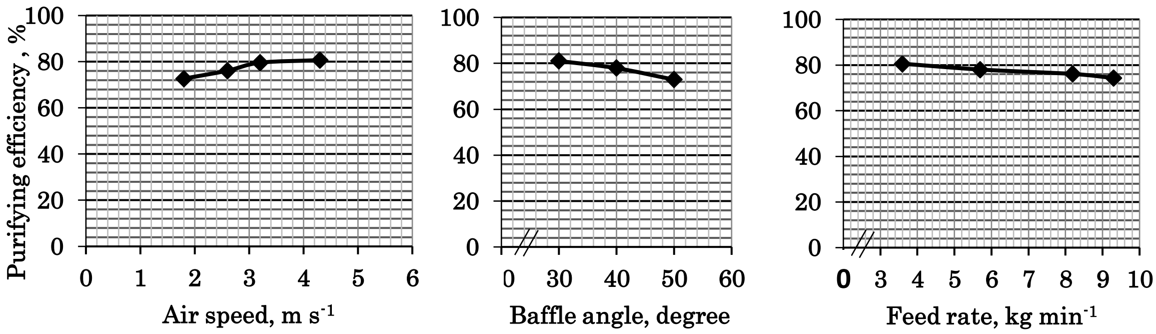

Figure 4. Effect of airspeed, baffle angle and feed rate on purifying efficiency, %.

Statistically, there's a highly significant difference between the tested factors of the purifying efficiency (Table 2). Also, the total interaction between different treatments shows a highly significant effect [P<0.05]. ANOVA analysis indicated highly significant differences between the treatments. A simple power regression analysis was applied to relate the change in purifying efficiency with the change in tested factors for all treatments. The obtained regression equation was in the form of:

ηP, % =90.78 - 1.0399 F. + 3.276 S. + 0.4073 A. (R^2= 0.8521).

[Where: Purifying efficiency (ηP, %), Feed rates (F), Airspeeds (S), and Baffle angles (A)]

Table 2. Means and standard errors for seed losses, % affected by studied factors.

Factors		Purifying efficiency, %
	S_1	72.67±1.674^a
	S_2	76.11±1.765^c
Air speed	S_3	79.58±0.655^b
	S_4	80.69±0.777^d
	P-value	0.0001
	A_1	81.02±1.266^b
Baffle angle	A_2	77.90±1.304^a
	A_3	72.88±1.178^c
	P-value	0.0001
	F_1	80.59±0.104^b
	F_2	78.03±1.544^a
Feed rate	F_3	76.11±1.174^b
	F_4	74.33±0.924^c
	P-value	0.0001

$^{a-b}$ the means with no common superscript within each column differed significantly (P<0.05).

Factors affecting losses, %

The data presented in Figure 5 shows the effect of airspeeds, baffle angles, and feed rate on the loss percentage. Decreasing airspeed decreases the mean losses from 3.76 at an airspeed of 4.3 m s^{-1} to 0.98% at an airspeed of 1.8 m s^{-1}. The lowest mean percentage of losses was 2.28 and 1.66 with 50° of baffle angle and a feed rate of 3.6 kg min^{-1}. The slight increase in the losses may be due to the increase in the angle of the border and the increase in the feeding rate, which lead to an increase in the scattering of the larger amount of the mixture, which gives a greater chance for the drift of the mixture exposed to the relatively high air stream.

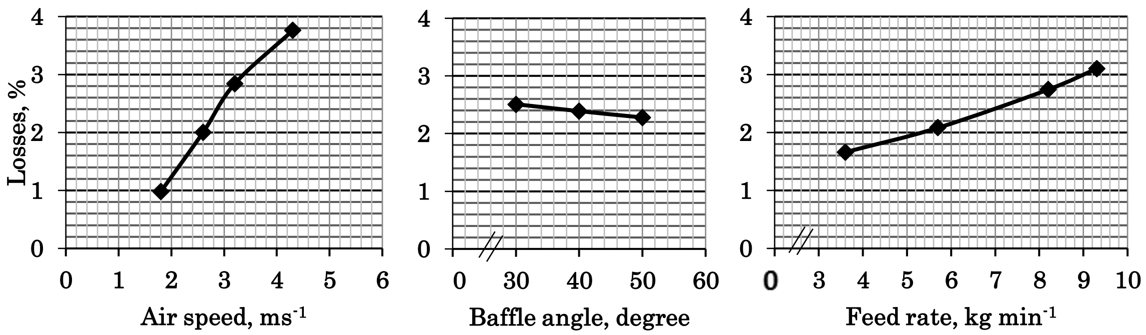

Figure 5. Effect of airspeed, baffle angle and feed rate on losses, %.

Also, the total interaction between different treatments indicates a highly significant effect of $P<0.05$ for the percentage of losses (Table 3). ANOVA showed highly significant differences between the treatments. Also, a simple power regression analysis was applied to relate the change in percentage of losses with the change in the tested factors for all treatments. [Where: Loss percentage (L, %), Feed rates (F), Airspeeds (S), and Baffle angles (A)]. The obtained regression equation was in the form of:

L, % = 1.214 - 0.2515 F. + 1.1196 S. + 0.01167 A (R^2=0.9067).

Table 3. Means and standard errors for losses, % affected by studied factors.

Factors		Losses, %
Air speed	S_1	0.98±0.014[d]
	S_2	2.00±0.016[b]
	S_3	2.84±0.005[c]
	S_4	3.76±0.010[a]
	P-value	0.0001
Baffle angle	A_1	2.51±0.066[a]
	A_2	2.39±0.004[b]
	A_3	2.28±0.008[c]
	P-value	0.0001
Feed rate	F_1	1.66±0.044[d]
	F_2	2.08±0.071[a]
	F_3	2.74±0.014[c]
	F_4	3.10±0.024[b]
	P-value	0.0001

[a-b] the means with no common superscript within each column differed significantly ($P<0.05$).

CHALLENGES AND FUTURE STUDIES

After purification of rice millers' residues, I find that I have a huge amount of light particles and fine dirt or dust. So, it is recommended to use it to improve soil properties and crop yield as mentioned by Anikwe (2000) and Njoku *et al.* (2011). We must also search for alternative sources of food for birds and fish due to the high price of forage.

CONCLUSION

This study investigated the posibitty of using weed seeds and broken rice grains as a special feeder for small birds. Four airspeeds, three baffle angles and four feed rates were studied. The maximum value of purifying efficiency (87.67%) was achieved at an airspeed of 4.3 m s^{-1}, a baffle angle of 30^o, and a feed rate of 3.6 kg min^{-1}. The minimum value of seed losses (0.4%) was achieved at an airspeed of 1.8 m s^{-1}, a baffle angle of 50°, and a feed rate of 3.6 kg min^{-1} So, it is recommended to use the purifying device at an airspeed of 4.3 m s^{-1}, a baffle angle of 30^o, and a feed rate of 3.6 kg min^{-1} to increase the purifying efficiency and use it at an airspeed of 1.8 m s^{-1}, a baffle angle of 50^o, and a feed rate of 3.6 kg min^{-1} to lessen seed losses.

DECLARATION OF COMPETING INTEREST

The author declares that he has no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author would like to declare that he solely developed all the sections in this manuscript.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1131804

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 214-230

Research Article

Design and Performance Evaluation of Canola-Seed Cleaning Machine

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ABSTRACT

Canola cleaning machine was designed depending upon the mechanical and aerodynamic separation theories. The designed machine was tested at three levels of cylindrical sieve angle 4, 7, and 10 degree and three levels of flat sieve speed 0.62, 0.88, and 1.08 m s^{-1}. The evaluation criteria included machine productivity *(MP)*, cleaning efficiency *(CE)*, percentage of seed losses *(P_{sl})*, specific consumed energy *(E_c)*, and germination percentage *(Gp)*. The results showed that the maximum values of *MP* and *CE* were 680.14 kg h^{-1} and 99.85 % respectively. While the minimum value of E_c was 5.88 kW h ton^{-1}. These values were achieved at cylindrical sieve slope angle 7 degree and flat sieve speed 0.88 m s^{-1}. Under these working conditions, the values of *MP, E_c* and *CE* were 680.14 kg h^{-1}, 5.88 kWh ton^{-1}, and 99.85%, respectively. Thus, the designed machine can be used with enough confidence to clean the canola seeds at cylindrical sieve slope angle 7 degree and flat sieve speed 0.88 m s^{-1}.

RESEARCH ARTICLE

Received: 16.06.2022
Accepted: 25.08.2022

Keywords:

- Canola seed,
- Separation,
- Mechanical,
- Aerodynamic

To cite: Ghonimy MI and Rostom MN (2022). Design and Performance Evaluation of Canola-Seed Cleaning Machine. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 214-230.* https://doi.org/10.46592/turkager.1131804

INTRODUCTION

Canola is considered one of the most important oil production crops in the world. It comes after palms and soybean as a source of world oil production. The oil extracted from canola seed is second only to olive oil in proportion of mono-unsaturated fatty acids and can be used in cooking, salad oils, edible oil blends, or as margarine (Longwic *et al.,* 2021). Canola oil is free from cholesterol and contains about 6%

saturated fats and about 94% (Statistical Year-Book, 2018). The canola cake which is the by-product left after the oil extraction is a protein rich meal that can be used in livestock feeding. Canola gives a good seeds yield in the new lands, but in fact, the harvested seeds yield contains some strange materials components such as sands, straw, … etc, which decrease the quality of extracted oil. Jenks (2000) stated that canola yields reduce by up to 77% if the weeds is not controlled. Rejection or serious price discounts may take place if the canola seeds were contaminated with wild mustard seeds. He added that the mechanical cultivation to remove weeds is not feasible, as canola is a shallow-seeded crop and tillage can injure canola seedling. El-Sayed *et al.* (2001) stated that canola crop which sowed by seed drill with a suitable row width of 400 mm gave the highest yield (3452 kg ha^{-1}) and the lowest consumed energy (9.45 kWh ha^{-1}) as compared with manual planting and planter. Oladimeji *et al.* (2020) considered Post-harvest losses (food lost from one stage to the other during handling) a major problem that faces the food production industry. Seed handling is a crucial piece of the complete innovation engaged with making accessible top notch seed. It guarantees the end clients, seeds of top notch with least defilement. In Agriculture, the term seed handling incorporates cleaning, drying, seed treatment, bundling and stockpiling (Oladimeji *et al.*, 2020). Simonyan and Yiljep (2008) mentioned that the frequency of sieve oscillations, amplitude of oscillation, sieve slope, length of sieve, sieve width, sieve holes diameter, fan speed, and angle/direction of airflow from the fan are the machine parameters affecting the cleaning and separating process. While, the crop factors included crop variety, seed moisture content, seed size, maturity stage, seed bulk density, straw moisture content, straw bulk density, stalk length, and terminal velocities of seeds and other materials. Serio *et al.* (2019) defined the terminal velocity as the air velocity required for seed suspense or balance. They mentioned that when seeds are exposing to air current through a certain path begin to move then remain constant at a certain velocity, at this velocity the net gravitational acceleration force equals the resistance upward drag force. At this velocity the seed is remains constant and in this case this velocity called terminal velocity. Binelo *et al.* (2019) used image processing and fluidized bed methods to find the values of terminal velocity of soya seeds, oat and maize. Gemeda (2020) evaluated Delta 114 cleaning machine of Oromia Seed Enterprise at two locations and he found that the highest values of cleaning efficiency were 96.89%, and 95.65% for wheat and barley seed while the lowest cleaning efficiency was recorded during bean cleaning was 80.22%. In addition, the minimum value of cleaning loss, 3.22%, was performed for wheat process while the maximum cleaning loss, 24.76%, was found for bean seeds. Alsharifi (2018) tested three threshing cylinder rotating speed; 200, 250 and 300 rpm for two types of maize threshing machines (Local MTL and MGI-TY 60). He reported that the threshing efficiency, cracked grain percentage, broken maize, grain cleaning, machine productivity, and power consumption were 83.9%, 4.0%, 6.0%, 88.8%, 1.96 ton h^{-1}, and 11.4 kW, respectively for Local MTL, while there were 83.3%, 4.4%, 6.8, 87.5%, 1.14 ton h^{-1}, and 12.2 kW respectively under the same operating conditions for MGI-TY 60. From previous studies, it is clear that seeds cleaning in general depends on the dynamic and aerodynamic properties of the seeds. Therefore, this study aimed to design and evaluate the performance of canola-seed cleaning machine based on the mechanical and aerodynamic separation theories.

MATERIALS and METHODS

Cleaning operation is defined as the final operation for seeds separation from the other blemishes (empty pods, straw particles and sand). These different components are separated according to several separation theories.

Selection of cleaning theory

There are several theories for seeds cleaning from the other blemishes. These theories are aerodynamic cleaning by using air from fan, mechanical cleaning by using sieves, aeromechanical cleaning and surface textures cleaning (Giyevskiy *et al.*, 2018).

The cleaning of canola-seeds from other blemishes (empty pods, straw particles and sand) could be achieved using mechanical and aerodynamic theories.

Mechanical cleaning

In this theory, the cleaning of canola-seeds from other blemishes depends upon the differences of the component's dimensions. Different scales sieves are used for cleaning operations. So, for this task, the mechanical cleaning unit was designed. It's consisting of three sieves one of them is cylindrical shape, moving in rotational movement to separate empty pods. The others are flat sieves moving in reciprocating movement for separating straw and some other blemishes. The function of these sieves is to accelerate the materials (empty pods and straw particles) to the exit hole. During this operation canola-seeds and fine sand moving to the aerodynamic separation unit through seed receiver.

Aerodynamic cleaning

The principle of aerodynamic theory depends upon the differences of terminal velocity and differences of drag coefficient of the different components. In this theory the cleaning is proceeding by pushing air current using a fan to separate canola-seeds from fine sand and any remain blemishes. Determination of drag coefficient and terminal velocity for canola-seeds are considered the most important factors for aerodynamic cleaning unit design.

Design of canola cleaning machine

The designed machine consists of the following main components, Figure 1.

Mechanical cleaning unit

The mechanical cleaning unit, Figure 2, consists of three sieves for the cleaning of canola-seeds from the other blemishes.

One of these sieves is cylindrical shape has a length of 1360 mm, 500 mm diameter and 5 mm holes diameter used for the separation of empty pods. The hole diameters were selected after the experimental determination of empty pods lengths and diameters which were 17 and 8 mm respectively. The empty pods and the other blemishes separation based on centrifugal force that generated from the rotational movement of the sieve besides the slope angle on the longitudinal axis of sieve. The optimum peripheral speed of the cylindrical sieve is 23 m s^{-1} equivalent to 878 rpm (Kepner *et al.*, 2005). The cylindrical sieve is connected with ball bearings fixed U-beam

(100 x 45 x 6 mm) at its end. This beam can be adjusted up and down for controlling sieve slope angle.

The other two sieves (flat type) were placed below the cylindrical sieve. The higher one has a length of 1500 mm, 700 mm width and 3 mm holes diameter. This sieve is used for completely separation of straw and empty pods. This sieve permits canola-seeds and fine sand to fall to the lower sieve. Receiver was fabricated to receive the empty pods and straw particles from the cylindrical and first flat sieve. This receiver has a reciprocating movement by crankshaft receiving movement from 100 mm diameter pulley fixed the end of the cylindrical sieve axis. This crankshaft was designed to give a stroke of 50 mm and rotating speed 820 rpm.

The lower sieve was designed with a total length of 2000 mm and total width of 700 mm. This sieve was divided into two sections. The first section has a length of 1500 mm and 0.5 mm holes diameter to keep canola-seeds above the sieve. The second section has a length of 500 mm and 5 mm holes diameter to permit for canola-seeds to go to the next cleaning unit. It has to be mentioned here that the two sieves are reciprocally moving by the reversible reciprocating arm. The flat sieves take the harmonic reciprocating motion by transmission shaft and eccentric crank in order to facilitate the transmission of canola-seeds to the seed's receiver then to the second separation unit (aerodynamic separation unit). The rotating speed of the transmission shaft to flat sieve could be determined from equation (1) according to (RNAM, 1995).

$$\omega = (\frac{2g}{r})^{0.5} \times 60 \qquad (1)$$

Where:

ω	=	Transmission shaft rotating speed, rad min^{-1};
r	=	Eccentric crank radius, m.
r	=	Eccentric crank radius, m.

Three values of r (50, 100 and 150 mm) were selected in order to determine the suitable transmission shaft rotating speed.

The flat sieve has a reciprocating harmonic motion with eccentric crank radius (50, 100 and 150 mm). This harmonic motion is represented in Figure 3. The flat sieve starts its reciprocating motion at point (a) the sieve forward velocity increased gradually to reach its maximum at the middle of the curve (point b), then its decreases gradually until it stops completely at point (c). This harmonic motion of the sieve occurs during 180 degree of eccentric crank. The average sieve speed was calculated from equation (2).

$$F_{ss} = \frac{S}{T} \qquad (2)$$

Where:

F_{ss}	=	Average speed of flat sieve, m s^{-1};
S	=	Sieve reciprocating stoke, m;
T	=	Time required for sieve reciprocating stoke = $30/\omega$, s.

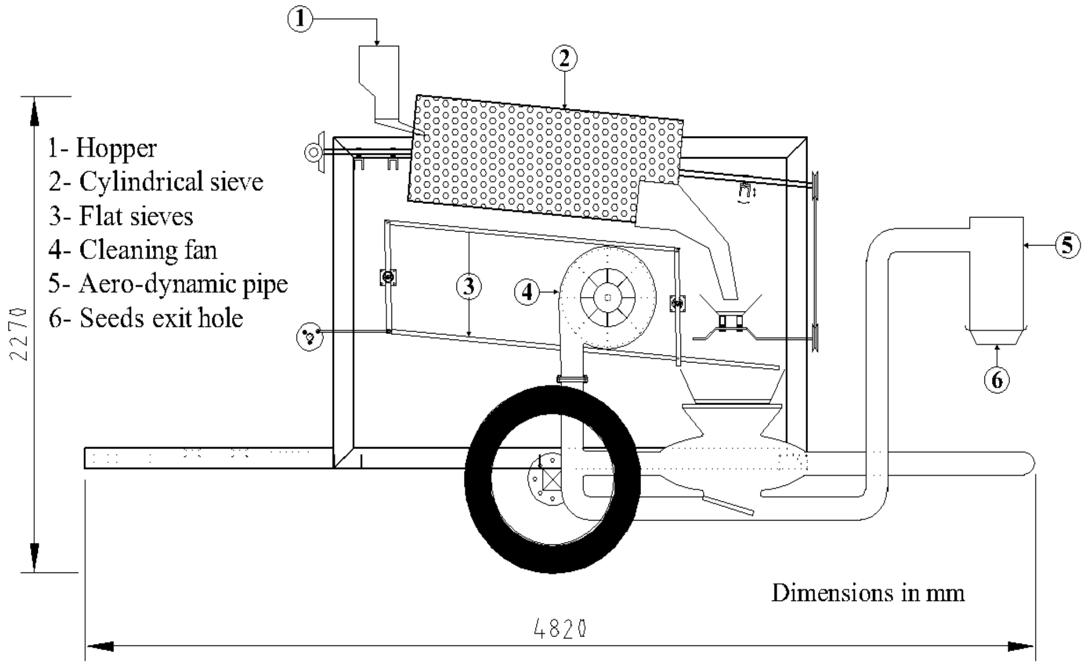

Figure 1. Canola-seeds cleaning machine.

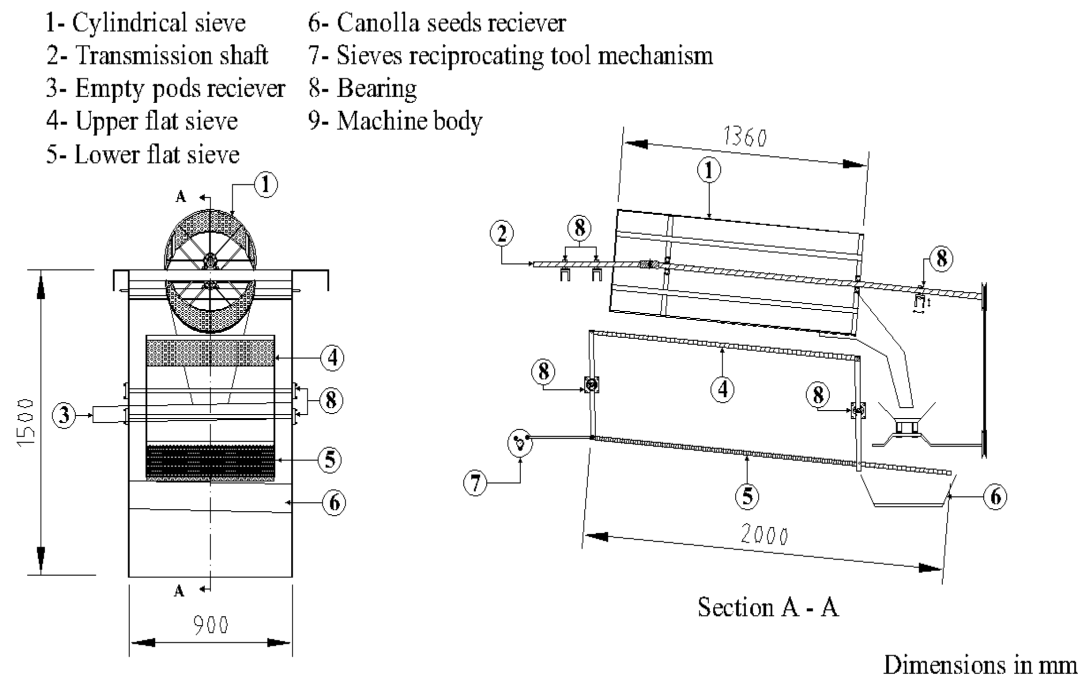

Figure 2. Mechanical cleaning unit.

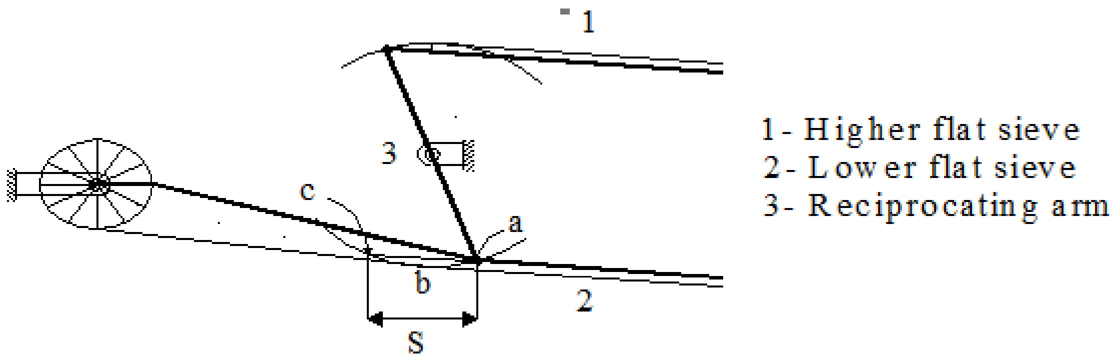

Figure 3. Flat sieve harmonic motion.

From Equations 1 and 2 and Figure 3, the values of F_{ss} were 0.62, 0.88 and 1.08 m s^{-1} that equivalent for eccentric crank radius 50, 100 and 150 mm.

Aerodynamic cleaning unit

Aerodynamic cleaning unit, Figure 4, receiving canola-seeds and fine sand from the mechanical cleaning unit through a conical hopper made from iron-sheet 3 mm thickness having 300 mm diameter at bottom and 500 mm diameter at the top. The design of aerodynamic cleaning unit based upon the determination of terminal velocity of canola-seeds. Where, the average value of terminal velocity was 7.23 m s^{-1} for canola-seeds. In this unit a fan with 500 mm diameter, 0.55 m^3 s^{-1} discharge and 950 rpm was used. This fan was connected with 125 mm diameter iron pipe.

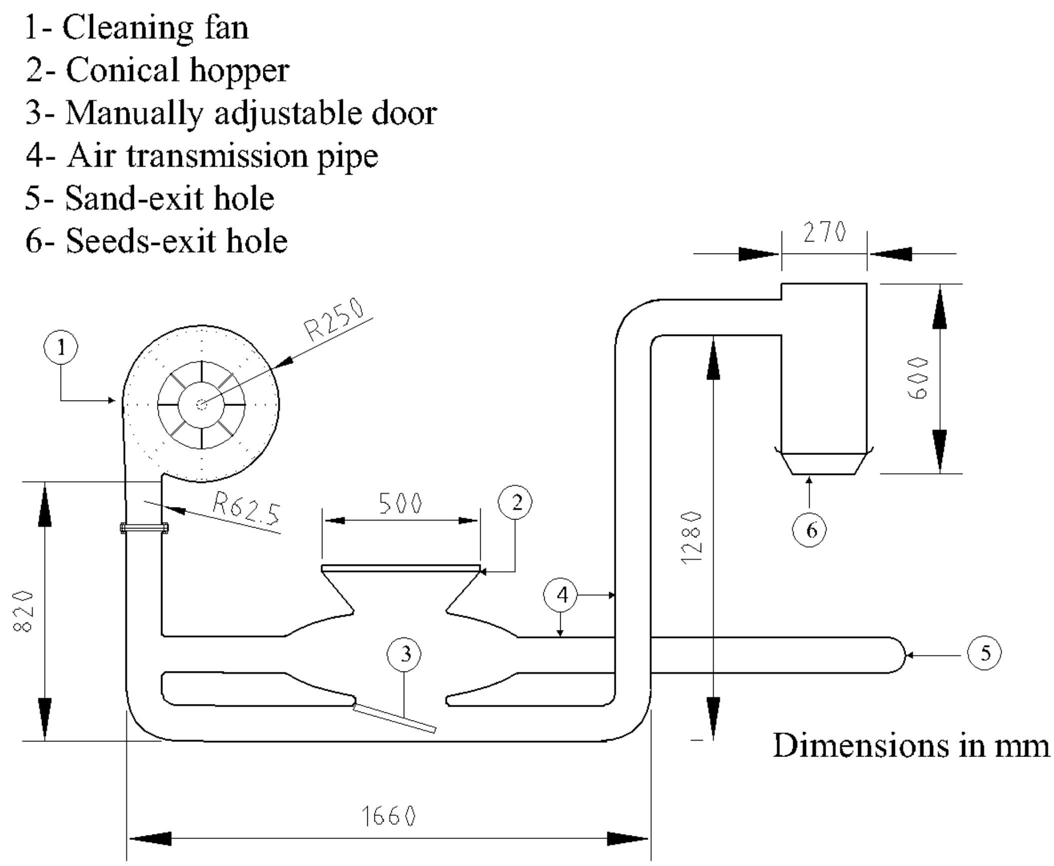

Figure 4. Aerodynamic cleaning unit.

Figure 5 shows the cleaning zone between canola-seeds and fine sand. The air path diameter at the section (A) was determined using Equation (3) where, the forward air velocity is equal to 4.3 m s^{-1} and it should be less than canola-seeds terminal velocity. The air velocity at section (B) is equal to 22 m s^{-1} and it should be more than seeds terminal velocity to cause a dragging force for canola-seeds toward exit hole. The manually adjustable door is used for controlling air velocity at the section (B).

Section (A):	Section (B):	Section (C):
Q = 0.28 m^3 s^{-1}	Q = 0.28 m^3 s^{-1}	Q = 0.55 m^3 s^{-1}
V = 4.3 m s^{-1}	V = 22.83 m s^{-1}	d = 125 mm
d = 280 mm	d = 125 mm	

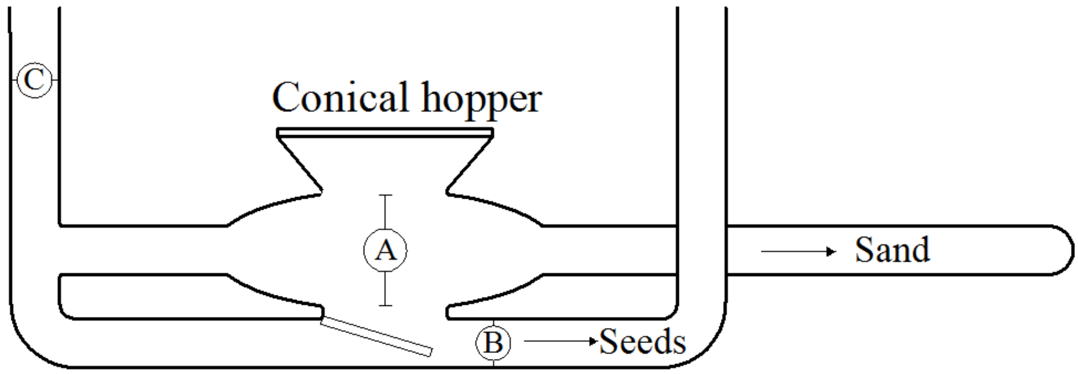

Figure 5. Separation zone between canola-seeds and fine sand.

$$d = \left(\frac{4q}{\pi V_t} \right)^{0.5} \tag{3}$$

Where:

d	=	Air path diameter, m;
q	=	Air flow rate, m^3 s^{-1};
V_t	=	Terminal velocity, m s^{-1}.

Feeding hopper

Feeding hopper was fabricated with a total capacity of 50 kg of canola-seeds. The feeding hopper was designed with a slope to allow easy movement of canola-seeds to cylindrical sieve.

Transmission system

Transmission system of canola cleaning machine was graphically presented in Figure 6. It consists of electrical motor (4 kW at 1330 rpm) as a source of power. This motor was connected with two pulleys 150 and 100 mm diameters.

The transmission system consists of four units. The first unit transmits the motion from electrical motor (using the 150 mm diameter pulley) to separation fan (950 rpm and 210 mm diameter pulley). The second unit transmits the motion from the electrical motor (using the 100 mm diameter pulley) to the cylindrical sieve using 270 mm diameter pulley fixed with shaft ending with two bevel gears 26 and 15 teeth respectively. The recommended rotating speed of the cylindrical sieve was 878 rpm according to Kepner *et al.* (2005). Hence, the final used bevel gear was 15 teeth; the rotating speed of the cylindrical sieve became 853 rpm. The third unit transmits the motion from the shaft No. 6 (transmission shaft to cylindrical sieve), Figure 6, to the flat sieves using 100 mm diameter pulley to 260 or 370 or 450 mm diameters pulleys that fixed with shaft No. 5 (transmission shaft to flat sieve) which rotates at 189 or 133 or 109 rpm respectively. The fourth unit transmits the motion from the end of cylindrical sieve shaft using 100 mm diameter pulley to straw and empty pods receiver using 100 mm diameter pulley.

The driving and driven pulleys diameters for each transmitting stage were determined according to the rotating speed of the driving and driven pulleys.

Open V-belts are used to transmit the motion between driving and driven pulleys. The length of V-belts is standardized by ANSI in U.S. customary units and SI units and was calculated according to Gope (2012).

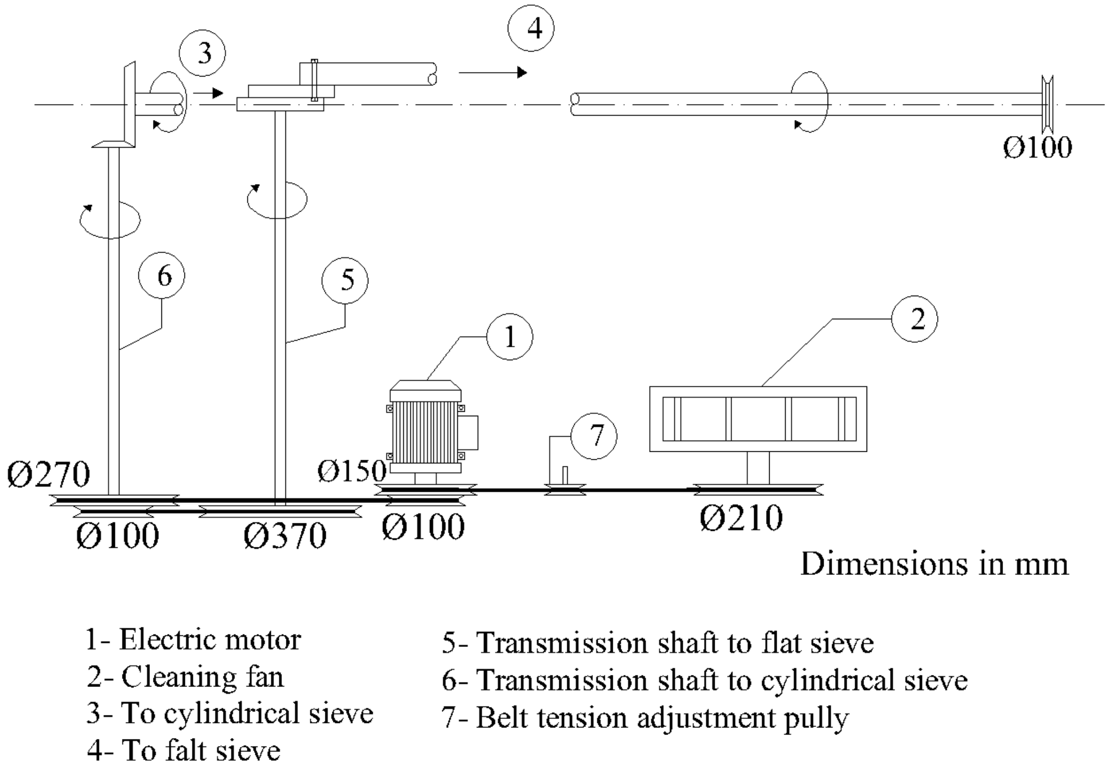

Figure 6. Transmission system.

Machine frame

The frame of canola cleaning machine, Figure 7, was manufactured from U-beam (100 x 45 x 6 mm). Machine sides were fabricated from iron-sheet 3 mm thickness. The total width for the canola cleaning machine was 900 mm, the total length was 4820 mm including the trailed arm and total height was 2270 mm including the higher part of cylindrical sieve.

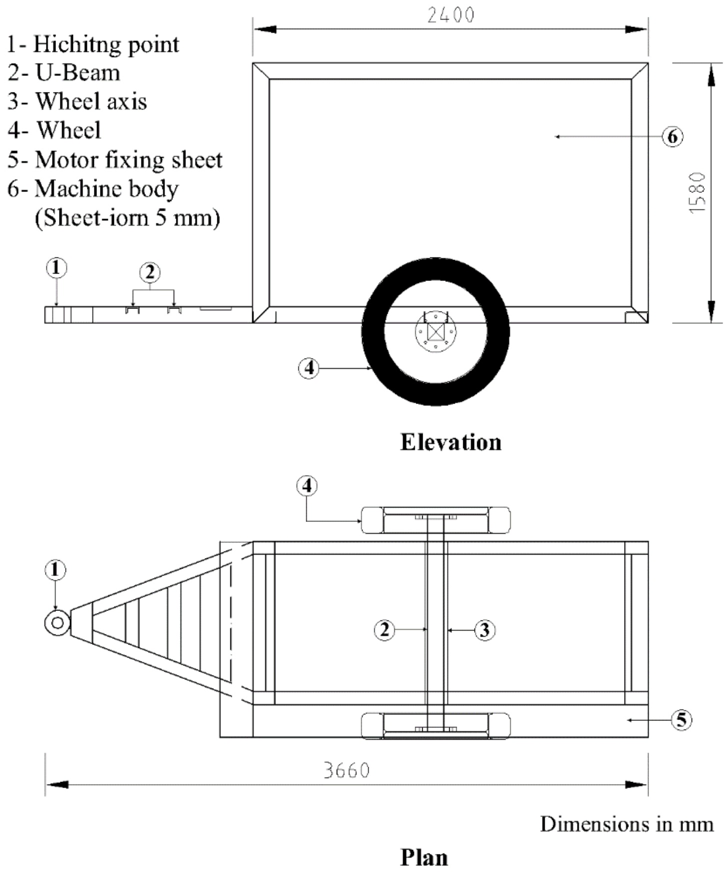

Figure 7. Machine frame.

The design of the rotating shafts

All rotating shafts for the canola cleaning machine were designed according to the stability of the shaft during rotation and not according to transmitted torque. The design of cylindrical sieve shaft were 2400 mm length and 45 mm diameter. The dimensions of the transmission shaft to cylindrical sieve were 750 mm length and 25 mm diameter while that for the transmission shaft to flat sieve were780 mm length and 25 mm in diameter. The diameter of each rotating shaft was calculated according to ASME code (Gope, 2012). Each rotating shaft was fixed to the machine frame through two ball-bearings. Field experiment was carried out at the experimental station farm, Faculty of Agriculture, Cairo University, Giza, Egypt to evaluate the designed canola seed cleaning machine.

Treatments

Cylindrical sieve slope angle (C_{ssa})

The tested values of cylindrical sieve slope angle were 4, 7 and 10 degree according to Kepner *et al.* (2005).

Flat sieve speed (F_{ss})

The tested values of flat sieve speed were 0.62, 0.88 and 1.08 m s^{-1} according to Kepner *et al.* (2005).

Measurements and Calculations

Canola seed diameter projected diameter and area

To find the drag coefficient *(Dc)* and drag force *(Df)* it was necessary to find the projected diameter and area of canola seeds. Using AutoCAD program and a digital camera, the projected diameter and area were determined by pasting a set of scattered seeds on graph paper. Using the AutoCAD program, the paper pasted with scale (1:1) on drawing worksheet. By drawing the outlines of the images, it was easy to get the projected diameter and area directly

Terminal velocity of canola-seeds

The terminal velocity of canola-seeds was measured according to the method described by Behroozi (2018). The air velocity was measured using air velocity meter (range, from 0.1 to 25.41 m s^{-1} and accuracy of 0.1 m s^{-1}).

Drag coefficient *(Dc)*

The drag coefficient of canola-seeds was calculated from Equation (4) according to Mohsenin (1970).

$$Dc = \frac{4gd_p(\rho_p - \rho_a)}{3\rho_a V_t^2} \tag{4}$$

Where:

Dc	=	Drag coefficient, - ;
d_p	=	Projected diameter, m;
ρ_p	=	Particle density, kg m^{-3};
ρ_a	=	Air density, kg m^{-3};
V_t	=	Terminal velocity, m s^{-1}.

Drag force *(Df)*

The drag force of canola-seeds was calculated from Equation (5) according to Mohsenin (1970).

$$Df = \frac{DC \times a \times \rho_a \times V_t}{2} \tag{5}$$

Where:

Df	=	Drag force, kg_f;
a	=	Seed projected area, m^2;
ρ_a	=	Air density, kg m^{-3};
V_t	=	Canola-seeds terminal velocity, m s^{-1}

Machine productivity *(MP)*

The machine productivity was calculated from Equation (6).

$$MP = \frac{S}{T} \tag{6}$$

Where:

MP	=	Machine productivity, kg h^{-1};
S	=	The total weight at seeds outlet, kg;
T	=	Consumed time, h.

Cleaning efficiency *(CE)*

The cleaning efficiency *(CE)* was calculated from Equation (7) (RNAM, 1995).

$$CE = \frac{S_1}{MP} \times 100 \tag{7}$$

Where:

CE	=	Cleaning efficiency, %;
S_1	=	Seeds weight at seeds outlet per unit time, kg h^{-1};
MP	=	Machine productivity, kg h^{-1}.

Percentage of seed losses *(P_{sl})*

The percentage of seed losses *(P_{sl})* was calculated from Equation (8) according to RNAM (1995).

$$P_{sl} = \frac{S_2}{FR} \times 100 \tag{8}$$

Where:

P_{sl}	=	Percentage of seed losses, %;
S_2	=	Weight of seed per unit time collected at all outlets except for seed outlet, kg h^{-1};
FR	=	Feed rate, kg h^{-1}.

Specific consumed energy *(E_c)*

The specific consumed energy *(E_c)* was calculated from Equation (9).

$$E_c = \frac{P}{MP} \tag{9}$$

Where:

E_c	=	specific consumed energy, kWh ton^{-1};
P	=	Motor power, kW.

Germination percentage *(Gp)*

The germination percentage *(Gp)* was experimented to test the effect of mechanical cleaning on the germination ratio, as this ratio is affected by invisible damage caused by mechanical cleaning. The *Gp* was calculated from equation (10) according to Sreekissoon *et al.* (2021).

$$Gp = \frac{N_g}{N_t} \times 100 \quad (10)$$

Where:

Gp	=	germination percentage , %;
N_g	=	Number of seeds germinated;
N_t	=	Total number of seeds sown.

Statistical analysis

The measured data for all variables were statistically analyzed by microcomputer program (CoStat ver. 6.400, 2008) via analysis of variance using complete randomized design (CRD), two factors model. The means of treatments were obtained, and differences were assessed with Student-Newman-Keuls at 5% level of probability.

RESULTS AND DISCUSSION

Canola-seeds characteristics

The values of canola-seeds diameter, density, terminal velocity and drag coefficient are shown in Table (1). From Table (1) it's clear that the average values of canola-seeds projected diameter projected area, moisture content, and density were 2.8 mm, 6.2 mm^2, 12%, and 0.65 g cm^{-3} respectively. The average value of terminal velocity was 7.23 m s^{-1}. Also, the drag coefficient value of canola-seeds was 0.39. While the drag force of canola-seeds was 1.01x10^{-5} N.

Table 1. *Some characteristics of canola-seeds.*

Characteristics	Value
Projected diameter, mm	2.8
Projected area mm^3	6.2
Moisture content, %	12
Density, g cm^{-3}	0.65
Terminal velocity, m s^{-1}	7.23
Drag coefficient,	0.39
Drag force, N	1.01*10^{-5}

Designed machine productivity *(MP)* and specific consumed energy *(E_c)*

The performance of the designed machine depends upon the cylindrical sieve slope angle (C_{ssa}) and flat sieve speed (F_{ss}). Figure 8 shows the effect of C_{ssa} and F_{ss} on the *MP* and E_c. From Figure 8 its clear that the maximum value of machine productivity (680.14 kg h^{-1}) and the minimum value of specific consumed energy (5.88 kWh ton^{-1}) were achieved at cylindrical sieve slope angle of 7 degree and flat sieve speed of 0.88 m s^{-1}. While the minimum value of machine productivity (590.64 kg h^{-1}) and the maximum value of specific consumed energy (6.77 kWh ton^{-1}) were found at cylindrical sieve slope angle of 4 degree and flat sieve speed of 0.62 m s^{-1}. From Figure 8 it's also clear that the productivity values of the designed machine increased by increasing of the cylindrical sieve slope value up to 7 degree and by increasing the flat sieve speed up to 0.88 m s^{-1}.

Through the above mentioned conditioned the *MP* and *Ec* values were in decreasing trend with the increasing of slope angle up to 7 degree. After that, the machine productivity decreased, and the consumed energy increased exponentially. These results were in agreement with the findings obtained by Priporov *et al.* (2021). They reported that to optimize in pneumatic systems of seed-cleaning machines, while increasing performance and improving the functional efficiency, it is necessary to improve their constructive and technological parameters. Improving pneumatic system parameters requires the development of a methodology for modeling the processes of airflow motion for their qualitative characteristics.

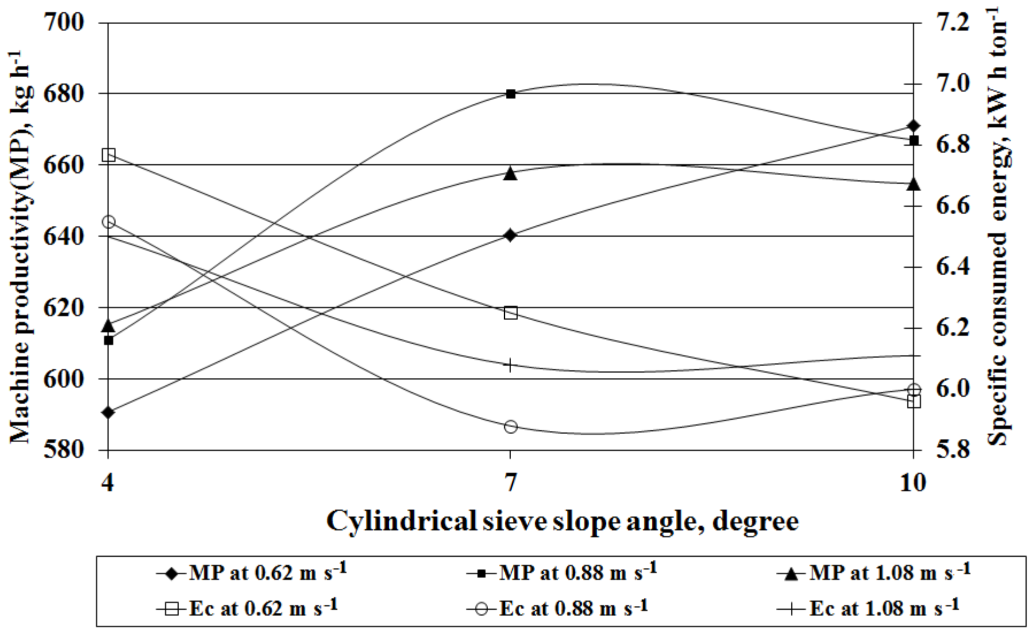

Figure 8. The effect of cylindrical sieve slope angle and flat sieve speed (F_{ss}) on the machine productivity and specific consumed energy.

Cleaning efficiency *(CE)*

The average value of cleaning efficiency *(CE)* of the designed machine is shown in Figure 9. From figure 9 its clear that the *CE* decreased by increasing of cylindrical sieve slope angle (C_{ssa}) and flat sieve speed (F_{ss}). At 4 degree of C_{ssa}, the *CE* decreased by 0.02 and 2.7% when the F_{ss} was increased from 0.62 m s^{-1} to 0.88 and 1.08 m s^{-1} respectively. The same trend was found at 7 degree and 10 degree of F_{ss}. At 0.62 m s^{-1} of F_{ss}, the *CE* decreased by 0.13 and 1.22% when the C_{ssa} was increased from 4 degree to 7 and 10 degree respectively. The same trend was noticed at 0.88 m s^{-1} and 1.08 m s^{-1} of F_{ss}. These results agree with the findings of Ali *et al.* (2022) they found that the maximum cleaning efficiency, 96.25%, was achieved at 5 m s^{-1} air velocity, 5° sieve slope, 1 kg min^{-1} feed rate, and 0.95 m s^{-1} sieve linear speed.

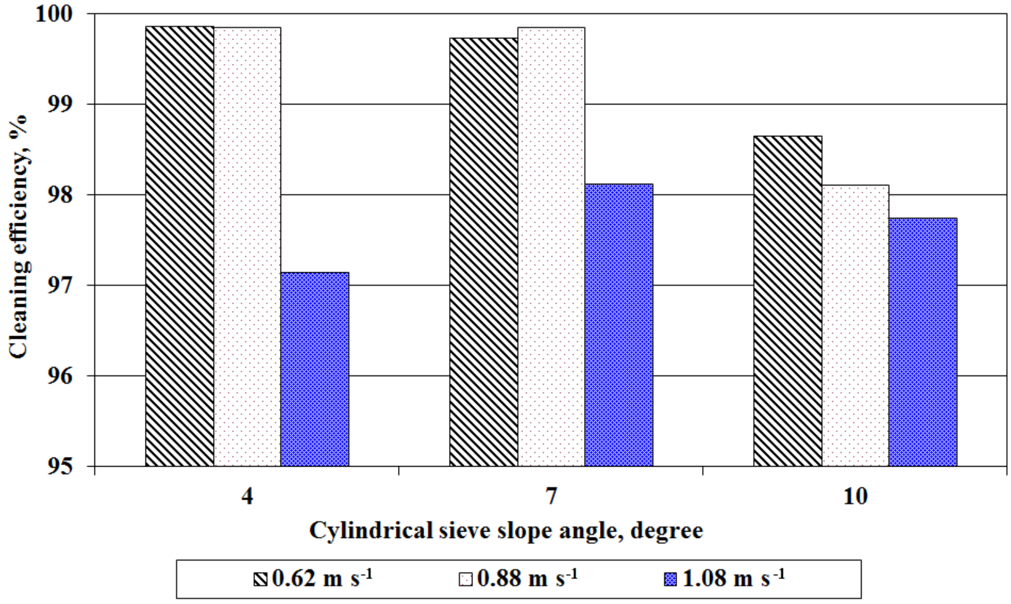

Figure 9. The effect of cylindrical sieve slope angle and flat sieve speed (F_{ss}) on the cleaning efficiency.

Percentage of seed losses *(P_{sl})*

The average values of P_{sl} are shown in Figure 10. From Figure 10 its clear that the P_{sl} increased by increasing of cylindrical sieve slope angle (C_{ssa}) and flat sieve speed (F_{ss}). The minimum value of P_{sl}, 3.71%, was found at 4 degree of C_{ssa} and 0.62 m s^{-1} of F_{ss}. While the maximum value of P_{sl}, 6.33%, was found at 10 degree of C_{ssa} and 1.08 m s^{-1} of F_{ss}.

At 4 degree of cylindrical sieve slope angle (C_{ssa}), the percentage of seed losses (P_{sl}) increased by 0.17 and 2.15% when the flat sieve speed increased from 0.62 m s^{-1} to 0.88 and 1.08 m s^{-1} respectively. The same trend was found at 7 and 10 degree of C_{ssa}. This increase might be due to the increase of canola-seeds acquainting kinetic energy resulted from the increasing of sieve speed. This acquainting kinetic energy caused the increasing of lost seeds percentage.

At 0.62 m s^{-1} of flat sieve speed, the percentage of seed losses (P_{sl}) increased by 0.31 and 2.22% when the cylindrical sieve slope angle increased from 4 degree to 7 and 10 degree respectively. The same trend was found at 0.88 and 1.08 m s^{-1} of F_{ss}. This increase might be referred to the increase of cylindrical sieve slope angle that increases the acquainting kinetic energy of the seeds with centrifugal force that caused increasing of seeds pushing towards blemishes receiver. Therefore, the percentage of seeds losses was increased. These results are similar to those found by Komil and Makhmud (2016), who reported that the seed losses ranged between 1.3 and 2.8% at 3 to 15 degree of sieve angle.

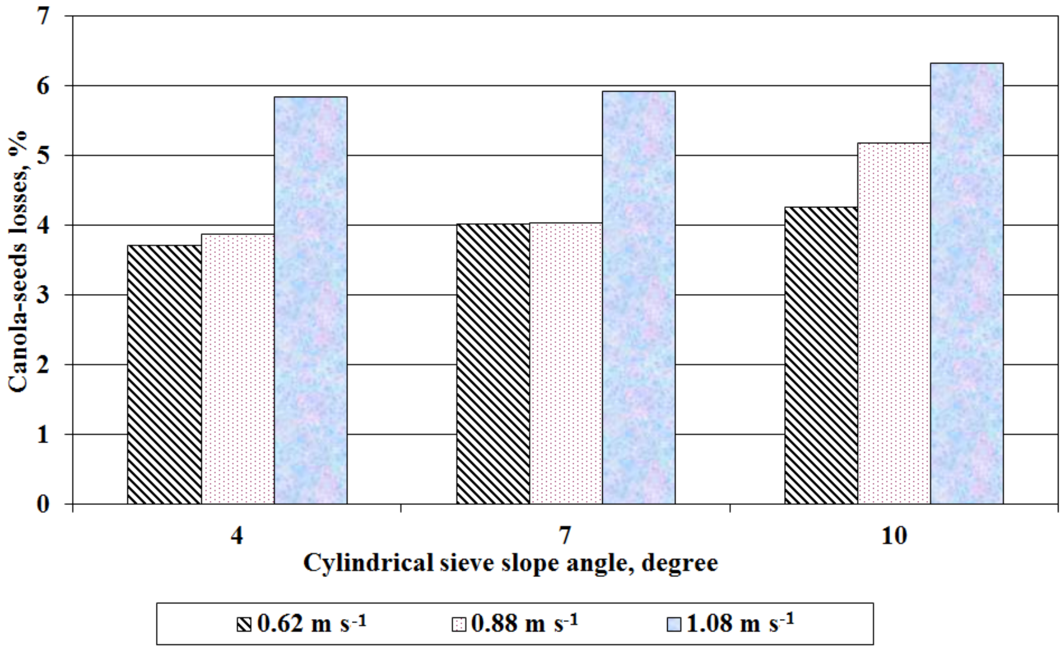

Figure 10. The effect of cylindrical sieve slope angle and flat sieve speed (F_{ss}) on percentage of canola-seeds losses.

Canola-seeds germination percentage (G_P)

Germination percentages of canola-seeds from seeds exit were determined and are illustrated in Table 2.

Table 2. *Germination percentage of canola-seed at different cylindrical sieve slope angle and flat sieve speed.*

Cylindrical sieve slope angle, degree	*Flat sieve speed, m s-1*	*Germination percentage, %*
4	0.62	97.0
4	0.88	99.5
4	1.08	98.3
7	0.62	99.2
7	0.88	98.3
7	1.08	98.6
10	0.62	98.0
10	0.88	99.1
10	1.08	98.2

From Table 2 its clear that the germination percentage of canola-seeds at seeds exit ranged from 97 to 99.5%. From Figures, 9 and 10 its clear that the optimum value of machine productivity (MP), specific consumed energy (E_c) and cleaning efficiency (CE) could be realized when cylindrical sieve slope angle was 7 degree and flat sieve speed was 0.88 m s^{-1}. Under these working conditions, the values of MP, E_c and CE were 680.14 kg h^{-1}, 5.88 kWh ton^{-1} and 99.85% respectively.

CONCLUSION

From this investigation the following conclusions can be done:

1. The terminal velocity of canola-seeds was 7.23 m s^{-1}.
2. The productivity of the designed machine increased by increasing of cylindrical sieve slope angle up to 7 degree and increasing of flat sieve speed up to 0.88 m s^{-1}.
3. The minimum value of specific consumed energy, 5.88 kWh ton^{-1}, deduced at cylindrical sieve slope angle of 7 degree and flat sieve speed of 0.88 m s^{-1}.
4. The maximum value of cleaning efficiency, 99.85%, was found at cylindrical sieve slope angle of 7 degree and flat sieve speed of 0.88 m s^{-1}.
5. The percentage of canola seed losses increased by increasing of cylindrical sieve slope angle and flat sieve speed.
6. The germination percentage of canola-seeds ranged from 97 to 99.5%.

DECLARATION OF COMPETING INTEREST

There is no conflict of interest between authors.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

This research work was carried out in collaboration with the authors (Ghonimy and Rostom).
Mohamed Ibrahim Ghonimy contributed equally in various roles including setting research goals, development of methodology, performing the experiments, analyzing data, and writing the artical and also coordinated the activities with the co-author.
Mohamed Naguib Rostom contributed equally in various roles including setting research goals, development of methodology, performing the experiments, analyzing data, and writing the artical.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1144063

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 231-244

Research Article

Design and Performance Evaluation of Grain Feed Grinding Machine

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ABSTRACT

The importance of milling grains into fine flours has a full advantage for homogeneity and size reduction for feed suitability. The grinding technology was made with locally available and affordable materials. Milling technology is promised technology mainly proposed for fish feed and can be used for any animals feed production that has been made with the factors considered in design standard and material properties. The hammer mill blades are replaceable or can regrind easily if they were worn out. This machine was designed and constructed for crushing locally available grains of maize, sorghum, wheat, barley, and other gains mainly for fish. And the parameters have been analyzed using statistix 8.0 software tool with different sieve hole-sizes (1 mm, 2 mm, and 3 mm) with corresponding independent variables; mass before and after grinding, grinding time, actual capacity, and crushing efficiency. The coefficient of variation of maize, wheat, and sorghum in respective sieve sizes for the grinding time and crushing efficiency was within the range of acceptable value of less than 7%. The power required for the milling has been determined 3000 W and the rotor speed was stepped up to 1800 rpm. The maximum capacity and crushing efficiency of this mill machine for different grains range from 65-78 kg h^{-1} and 90-95% respectively.

REVIEW ARTICLE

Received: 29.07.2022
Accepted: 19.09.2022

Keywords:

- Hammer mill,
- Blade shape,
- Sieve size,
- Efficiency

To cite: Desta MA and Oumer A (2022). Design and Performance Evaluation of Grain Feed Grinding Machine. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 231-244.* https://doi.org/10.46592/turkager.1144063

INTRODUCTION

Ethiopia is a country blessed with immense livestock and fishery resources. Obviously, the nation has an enormous livestock population in Africa and is ranked fifth in the world. The livestock industry continues to be one of income generation and subsidizes over 40% of the nation's agricultural GDP regardless of receiving modest state investments over the years. Ministry of livestock and fishery stated that industries are essential to the country's socio-economic development goals as it works toward its goal to become a middle-income country by the end of 2025 (Gashaw, 2018).

In the country of Ethiopia, it contains about 7000 km of rivers and 7400 km^2 of ponds. Ethiopia has a volume of capacity 51.500 tones of fish annually, however approximately 30-38% percent of this volume is present used. The issue varies by location but is most significantly affected by infrastructure, marketplace, and feedstuff (Tesfahun *et al*., 2018). Food for fish could contain a protein combination of 30-40% with substantial amount of lipids to provide a high level of fish production (Admasu *et al*., 2019).

The general algorism and algebraic mathematical formulations were used in equivalent to different proportion of easily accessible ingredients such as wheat bran, sorghum, and barley. The constituents were then considered as protein & vigor basis materials. These formulae have allowed for the achievement of the target crude protein and energy stages (Admasu *et al*., 2019).

Fish weight can be varying by using different feed nutrients. Majorly the diets were made from various protein-rich compositions of wheat, barley, and oats with a protein range from 11–14%. Efforts were made especially for feeding classes that are elevated and which make up unevenly 60% of the fish meal eat in fish industry (Suresh *et al*., 2018).

Today, the most of milling technology is designed for large scale productions of feed and particle mills. However, anyone operating on a small-scale faces difficulty in growing their own business. As a result, there is a significant need for small-scale milling equipment (Adekomaya *et al*., 2014).

Most of the conventional grain mill machines are used to convey grain and then re-circulate the uncrushed grain material, re-grinding it. But the machine that has a curved end screen hammer. Though, there no conveyance of un-milled particles that was used in the study when rectangular with serrated tip screen hammers mills to allow for entry. The research proves the efficiency of hammer mills with curved ends and serrated flat screens (Ajaka *et al*., 2104).

Milling is the process of converting large size grain materials into fine particle sizes. Materials are reserved in a crushing chamber until sieve allows entering the ingredients and lowered. The quantity of crushing on the rotating shaft unit, the dimension, structural arrangement, end shapes/sharpness, the rotational speed, wearing effect, and the available clearance between the tips with respect to the screen are the significance factors on the grinding capacity (Higgs *et al*., 2011).

The main objective of this study is to design and performance evaluation of grain grinder machine with efficiency greater than 89% with minimum costs and simple repair. This is to modify the most familiar hammer blades with a curved end (semi-circle) hammer mill tip, to a two-sided shape and tip serrated screen beat mill allocated as a major feature factor.

MATERIALS and METHODS

Sources of experiment

The investigation was conducted at the Melkassa Agricultural Research Center in Ethiopia's Oromia regional state. Its geographical coordinates are 8° 24' 985 N and 39° 19' 529 E, and its elevation is 1550 meters above sea level.

Fish feeds with wheat ingredients kinds are considered appropriate for the suspending of feeds. As alternatives, maize could be suitable for flour grinder with correct screen will be preferred or if it has made based on the present design. Moreover, the grain crusher machine has been tested on representative feed substances like wheat, sorghum, brewery waste, nug-cake, maize, and wheat bran that as a fish research center recommended (Admasu *et al*., 2019). According to (Zhou, 2018) the particle size for animal feed of plate size holes were between the ranges of 1 mm-5 mm.

Statistix 8.0 design software was used for data analysis as long as RCBD design has been considered for the experimental design. During testing, the machine performance was determined by varying the sieve size with a constant weight for each ingredient initial sample items (2 kg) with variation grinding time, the overall capacity and efficiency of the machine was determined. The test was conducted on maize, wheat and sorghum grain ingredients.

The main parts of the grain feed grinder machine consist of;

- ✓ Hopper
- ✓ Driving beat hammers
- ✓ Driving unit holder to hold the hammer beaters
- ✓ Driver and driven pulleys'
- ✓ Motor with belt
- ✓ Bearing, bearing and other housings and frames.
- ✓ Different sieves to separate the ingredient particle size

Machine component design

In the design mill machine components, some parameters have been considered such as ease of maintenance, affordable, and locally available materials within the capacity of medium scale farmers.

Hopper unit

This unit is configured by considering the overall capacity of the machine. The hopper must be capable to provide adequate grains in order to achieve all through the capacity. This has pyramidal shape and prepares with a sheet metal 2 mm thick. The hopper size was 50 * 50 cm on the top sides, 15 * 15 cm on the bottom opening, and 30 cm depth.

Frame and support

The frame part was manufactured using mild steel material with square pipe cross-sections (50*50*3) mm. The overall dimensions are 68 cm length, 50 cm width, and 80 cm height.

Determining of shaft speed

One must first choose the rotating speed and overall capacity while designing a hammer mill. According to (Stephens *et al.* 2005), it has been decided that a beat mill with an output speed of about 1800 rpm will result in better competence. Based on this, pulley drives could be used to raise the output speed of the majority of commercially accessible motors, which have an output speed of 1440 rpm.

Starting with the assumption that the motor pulley diameter is around 160 mm, one can use the relation provided in Equation (1) using the theory of (Mohamed *et al.*, 2015).

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \tag{1}$$

Where: D_1, driver pulley diameter, m; D_2, driven pulley diameter, m; N_1, rotational speed of motor, N_2, driven rotational speed. This gives the result to step up the speed to about 1800 rpm and driven pulley diameter can be used as 128 mm. And the results are $D_1 = 0.16$ m, $D_2 = 0.128$ m, and $N_1 = 1440$ rpm.

Determining of belt length and contact angle

The belt contact length can be calculated by considering driver, driven pulley diameter, and center distance between them. It was calculated in the Equation (2) using (Ezurike *et al.*, 2018).

$$L = 2C + \frac{\pi}{2}\left(D_1 + D_2\right) + \left(\frac{D_1 - D_2}{4C}\right)^2 \tag{2}$$

Where, L is belt length, mm; C, distance between smaller and larger pulley's (directly measured from the final fabricated technology) as 400 mm.

Substitute all the required values gives,

$$\mathrm{L} = 2(400) + \frac{\pi}{2}\left(160 + 128\right) + \left(\frac{160-120}{4\,(400)}\right)^2 = 1252\ mm$$

The contact angle of belt can be calculated in considered to the pulley's using relations of (Ezurike *et al.*, 2018).

$$\beta = sin^{-1}\left(\frac{R-r}{2C}\right) \tag{3}$$

Where, R, larger pulley radius, r is smaller pulley diameter, mm; β, contact angle.

$$\beta = sin^{-1}\left(\frac{84-60}{400}\right) = 3.4^{\circ}$$

The angle of wrap is gives,

$$\alpha_1 = \pi + 2\beta \qquad \text{for diver pulley} \tag{4}$$

$$\alpha_2 = \pi + 2\beta \qquad \text{for driven pulley} \tag{5}$$

Therefore, $\alpha_1 = 180 + 2 \times 3.44^{\circ} = 188.8°$ and $\alpha_2 = 180 + 2 \times 3.44^{\circ} = 173.1°$

Where, θ_d, smaller pulley contact angle in deg, θ_D larger pulley contact angle in deg *D*, larger pulley diameter, mm; *d*, smaller pulley diameter, mm; α_1, angle of wrap for driven pulley, α_2, angle of pulley for driver pulley.

The torque transmitted (pulley torque) can be the same as half of the total added forces *(F)* and the difference between F_1 and F_2 is related to the pulley torque *(T)* can be given the Equation (6), (7), and (8) using the mathematical formula of (Stephens *et al.*, 2005).

$$F1 - F2 = \frac{2T}{D} \quad (6)$$

Where, F_1 tight side tension, N, F_2 loose side tensional force, N, *Fc* centrifugal push force, N, *Fi* initial tension, N.

The centrifugal force could be determined as

$$Fc = mv^2 \quad (7)$$

From this, it is likely to calculate the belt's extreme tensional force as *(T=SA)*; where *S* is the maximum tolerable belt stress. For leather belting, the permitted tensile stress ranges between 2.4 MPa-2.45 MPa. Once more, the belt area might be expressed as,

$$A= bt \quad (8)$$

Where, p = density of belt (1000 kg m^{-3}) for the common belts, the selected width and belt thickness have 12.5, 8 mm respectively. For the calculated belt tension is *T* = 2304 N and the motor linear speed can be given as follows (Stephens *et al.*, 2005).

$$V = \frac{\pi dn}{60} = 12\ m\ s^{-1} \quad (9)$$

The centrifugal force (*Fc*) can be calculated using the hammer tip velocity (*v*) and mass per unit length, where *Fc*=129.6 N.

The equation is used to calculate the power and torque applied to the shaft as well as the intended power needed by the shaft will be calculated using (Gupta and Khurmi, 2005). Accordingly, to this statement, the tensional force (F_1) was three times of centrifugal force. Therefore, the tight side force will give, F_1 = 3Fc = 388.8 N.

$$P = (F_1\text{-}F_2)\ V) \quad (10)$$

Again, the slack side force (F_2) can be calculated using the equation of

$$\frac{F_1}{F_2} = e^{\beta\mu} \quad (11)$$

Where, β, is angle of wrap in degree and μ, frictional coefficient between belt & pulley assumed to use as 0.3 and 3.44 respectively. Therefore, the slack side force (F_2) value will be 138.8 N. By adding the power Equation (7) the value of motor power will give 3 kW.

Determining weight of hammers

Hammers can be designed by considering the impact of centrifugal forces can be calculated using the formula of (Stephens *et al.*, 2005).

$$F_h = N_h * M_h * r_h * \omega_h^2 \quad (12)$$

Where, F_h Centrifugal force, Kn, r_h radius of hammer blade, 0.125 m. ω_h angular velocity, 188.4 rad·sec, $\left(\frac{2\pi N}{60}\right)$, N_h, number of hammers, 16 N, velocity of hammer (1800 rpm).

The weight of hammer blades could be up to 0.2 kg (Euzrike *et al.*, 2018)

$$W_h = M_h \cdot g \quad (13)$$

Where, W_h is weight of hammer blade, kg, M_h, mass of hammer blade, g, gravitational acceleration (9.81 m s^{-2}). This result gives the weight of blade has been 2 kg m^{-2}. For a better grinding efficiency, the quantitative number of hammers could be up to 16 The yield and tensile strength of the material is about 351 Pa and 421 Pa respectively. And, the mathematical formula utilizing for the density is about 7860 kg m^{-3} as well as the minimum width of the hammer mill (w_h) to withstand the impact of centrifugal force (Stephens *et al.*, 2005).

$$M_h = \rho * V_h \quad (14)$$

Where, ρ is density of material (7860 for mild steel), kg m^{-3}, V_h is volume of hammer (0.125 m × 0.005 m × 0.05 m).

Determining the shaft sizes, calculating the shaft diameter using the general Equation (12) using the formula of (Nisbett *et al.*, 2010).

$$\frac{1}{n} = \frac{16}{\pi d^3}\{\frac{1}{S_{ut}}[(4(k_b M_b)^2 + 3(k_t M_t)^2]\}^{\frac{1}{2}} \quad (15)$$

Where, d, diameter of shaft in m, M_b, bending moment N · m; M_t, torsional moment, N m; k_b and k_t are combined shock and fatigue factors for bending & torsion respectively using American Society of Mechanical Engineering (ASME). And the values for the combined shock bending and torsional moments were taken 1.5 & 1.0 for the gradually applied shaft stress.

Mild steel with the characteristics S_{ut} = 420 Mpa and S_y = 351 Mpa was utilized to create this design. The torque generated by a 3 kW motor is what exerts force on the shaft, and the weight of the blade-containing disc is what exerts force vertically.

Therefore, the bending moment can calculate by using the vertical bending moment diagrams of the shaft (M_t) calculated using the mathematical theory of (Gupta and Khurmi, 2005).

$$M_t = \frac{P*60}{2\pi N} \quad (16)$$

Using the transmitted power of 3000 W and rotational speed of 1800 rpm the bending moment gives,

$$M_t = \frac{3000\ W*60}{2\pi*1800\ rpm} = 15.9\ \mathrm{N \cdot m}$$

On the other hand, the vertical loading bending moment could be using the centrifugal force exerted by the hammer as 1300 N (upward). And the shaft is subjected to the vertical applied load. Therefore, the values of distributed vertical force will be per unit length of loaded shaft=$\frac{1300\ N}{0.28\ m}$ =4642.8 N · m^{-1}

Mass of each blade =0.2 kg and the quantity are 16 and the weight of each blade contains=2.0 kg, Again the vertical force can be obtained by considering the factor of safety=2.5, the minimum shaft length and diameter is determined as 280 mm and 30 mm respectively.

Figure 1 shows the diagram for free body and bending moment as well to determine the bending moment at point of bearing support, it is clear that the maximum bending moment is in the point of A with bending moment M_b=4642.8 × $\frac{0.28^2}{2}$=181 N · m

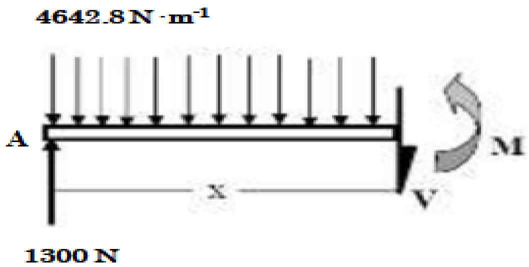

Figure 1. Free body diagram and bending moment.

By applying in Equation (15) both the maximum bending moment (M_b) and vertical applied load (M_t), the shaft diameter to carry out these forces should be greater than or equal to 30 mm.

Bearing selection

The function of bearing is to carry loads and to bring the auxiliary structure. The following material properties have been considered during bearing selection, corrosion resistant, resistant to damage during rotational speed, strong enough to carry loads, static friction, and optimum operating temperature. According to (Nisbett *et al.* 2010) for the medium operating machines like milling, it would have maximum speed up to 2000 rpm and the maximum load 15000 psi. Using manufacturing catalogue ball bearing type has been selected for this purpose.

Based on the design parameters the assembly, orthographic views, and part drawing of the prototype will be shown in the Figure 2 to 8.

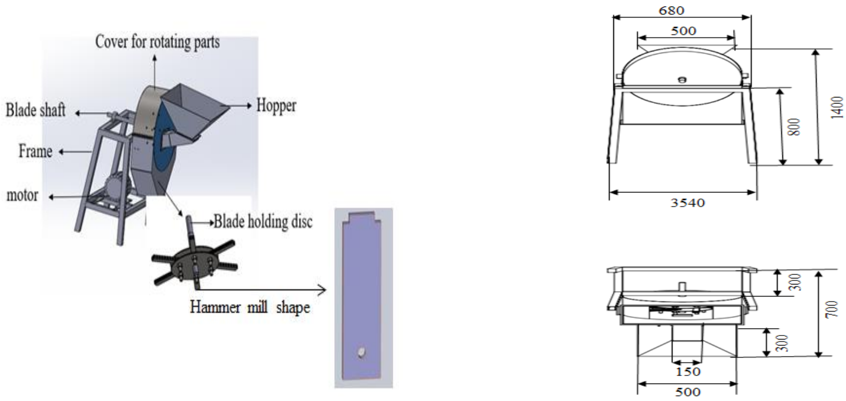

Figure 2. Assembly and engineering drawing views of hammer mill.

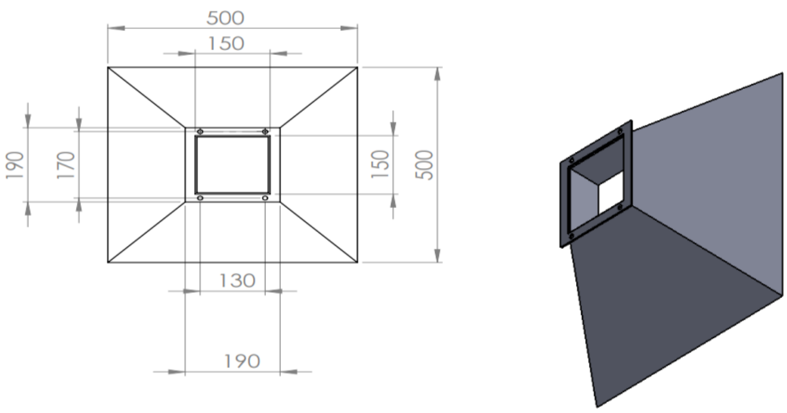

Figure 3. Orthographic and isometric drawing of hopper.

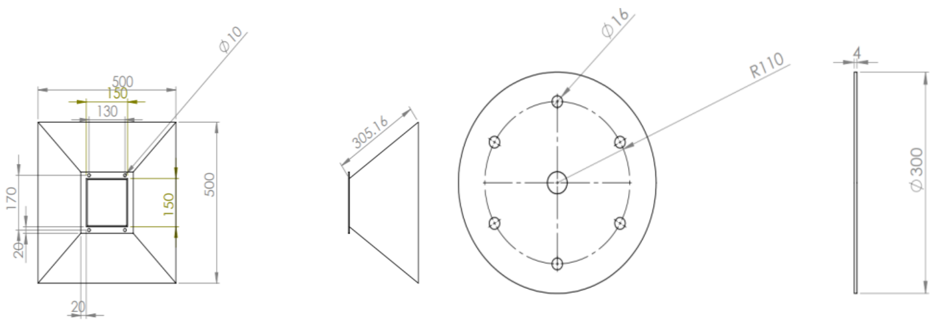

Figure 4. Top and side views of hopper and rotor disc respectively.

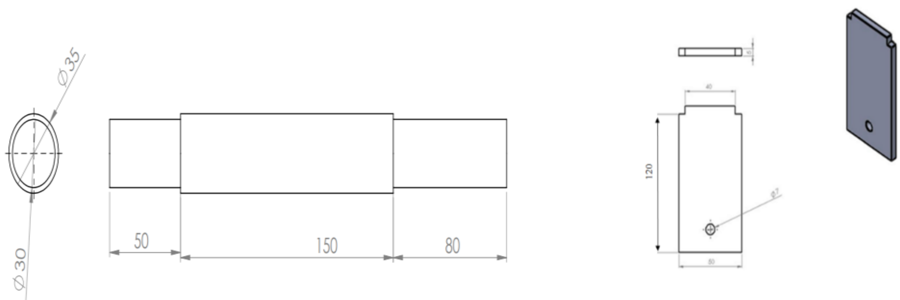

Figure 5. Top and side views of shaft and hammer mill respectively.

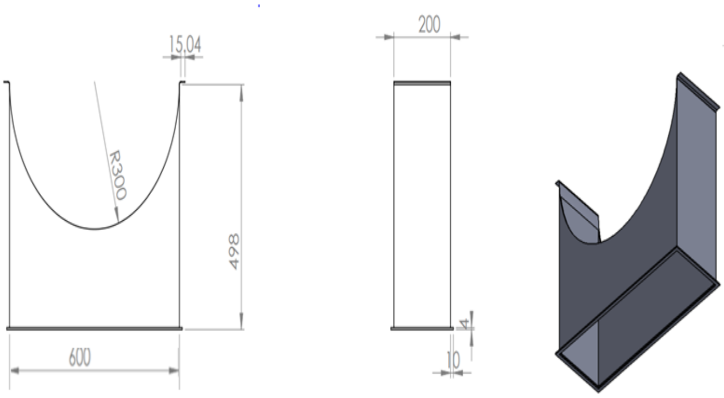

Figure 6. Orthograpic and isometric views of grain discharge.

The machine was designed using solid-works design software tool and proper material selection was done before the real assembling and construction of parts.

Figure 7. Pictures of fabricated hammer mill machine.

Figure 8. Picture during separation on different sieve sizes of sample flour.

Measuring tools

i. Weighing balance: in order to measure the mass of ingredients (before and after milling)
ii. Stopwatch: for the purpose of recoding for the time of milling
iii. Tachometer: in order to measure the speed of the rotor hammer mill.
iv. Different sieves sizes: (1 mm, 2 mm, and 3 mm)

The mathematical Equation (17) & (18) crushing efficiency and losses has calculated by using (Mohamed *et al*., 2015).

Crushing efficiency

Crushing efficiency can be computed using the expression given,

$$Crushing\ efficiency = \frac{mass\ of\ recovered\ material}{mass\ of\ input\ material} x100 \qquad (17)$$

Loss

$$Loss = \frac{Mb - Ma}{Mb} \qquad (18)$$

Where, M_b= Mass before grinding, and Ma= mass after grinding

RESULTS and DISCUSSION

The milling technology can be used for multipurpose of animal feed mixing as well as milling. Specifically, this research has been conducted only on fish feed sample ingredients of wheat, maize, and sorghum. The prototype of the machine has been produced and most of the machine parts use locally accessible materials. Preliminary testing of the milling is targeted at evaluating its ability to grind different size ingredients, duration of milling, capacity, and crushing efficiency have been considered. Figures 9, 10, and 11 illustrates the relationship between machine grinding efficiency and time of crushing for wheat, maize, and sorghum ingredients respectively. Different efficiency values have been gained according to the ingredient type to be crushed.

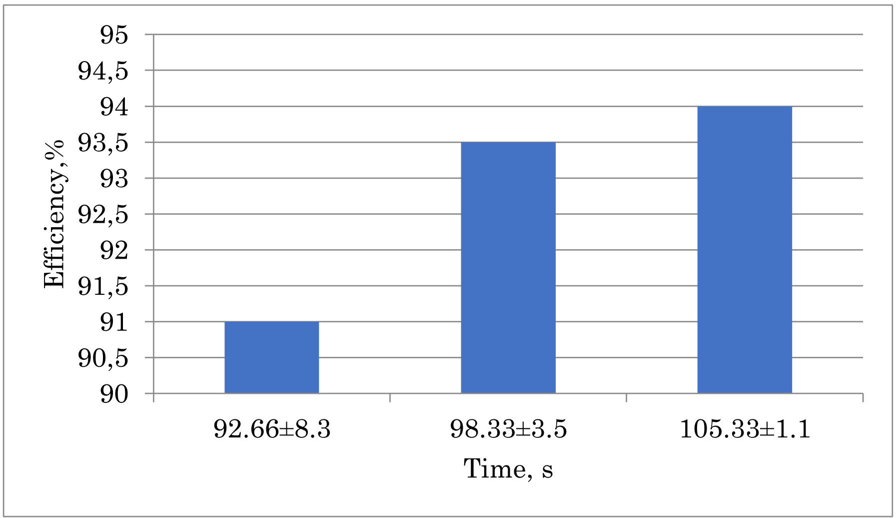

Figure 8. Average crushing efficiency versus time for wheat.

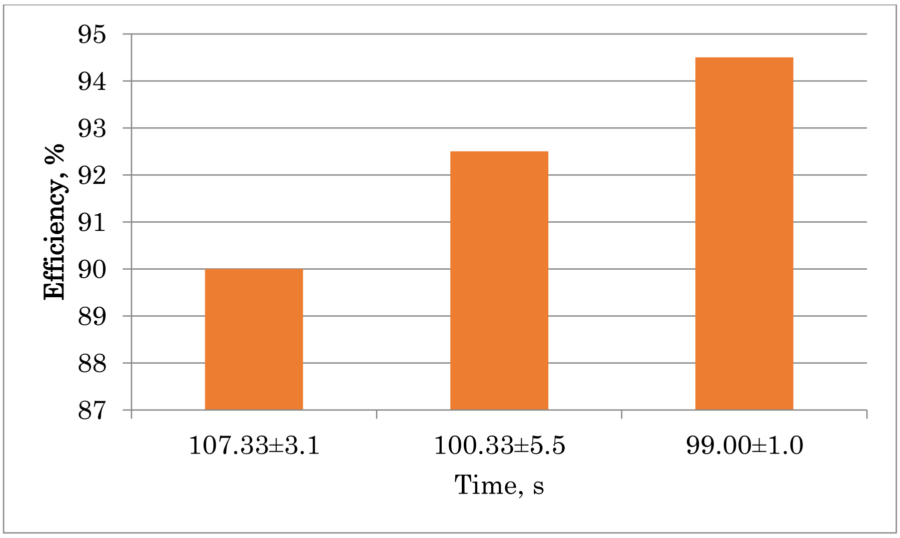

Figure 9. Average grinding efficiency versus time for maize.

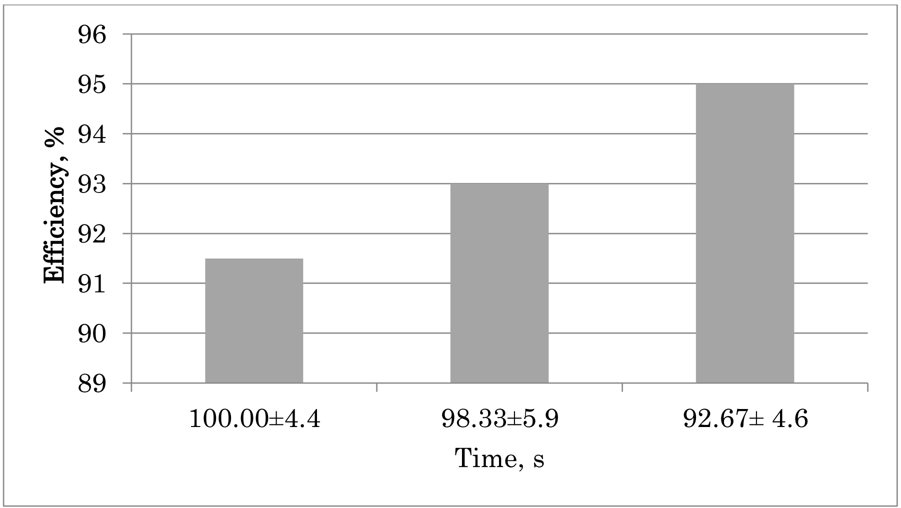

Figure 10. Average grinding efficiency versus time for sorghum.

Table 1. Sample test result for maize

Parameters				
Sample sieve	Sieve # 1 (1 mm)	Sieve # 2 (1.5 mm)	Sieve # 3 (2 mm)	CV
Mass (kg)	2	2	2	
Mass after grind, kg	1.8±0.05	1.85±0.04	1.89±0.02	
Capacity, kg $\cdot$ h^{-1}	67.13±1.88A	71.90±3.95A	72.73±0.75A	3.72
Crushing efficiency, %	90	92.5	94.5	
Loss, %	10	7.5	5.5	

Letter “A” indicates that the level of average mean followed by the same letters is not significantly different.

Table 2. Sample test result for wheat

Parameters				
Sample sieve	Sieve # 1 (1 mm)	Sieve # 2 (1.5 mm)	Sieve # 3 (2 mm)	CV
Mass, kg	2	2	2	
Mass after grind, kg	1.82±0.06	1.87±0.05	1.88±0.04	
Capacity, kg h^{-1}	73.300±2.60A	78.100±6.75A	68.40±0.69A	6.49
Crushing efficiency, %	91	93.5	94	
Loss, %	10	7.5	5.5	

Letter "A" indicates that the level of average mean followed by the same letters is not significantly different.

Table 3. Sample test result for sorghum

Parameters				
Sample sieve	Sieve # 1 (1 mm)	Sieve # 2 (1.5 mm)	Sieve # 3 (2 mm)	CV
Mass, kg	2	2	2	
Mass after grind, kg	1.83±0.06	1.86±0.04	1.9±0.02	
Average capacity, kg h^{-1}	72.100±3.05A	73.400±4.23A	77.83±3.75A	4.46
Crushing efficiency, %	91.5	93	95	
Loss, %	8.5	7	5	

Letter "A" indicates that the level of average mean followed by the same letters is not significantly different.

According to (Aboud, 2012) study has conducted to see the effect of drilled sieve holes ranges 1 to 3.5 mm for maize, wheat, and barley ingredients. Discussed about the result, as increase in sieve size diameter from 1 to 3.5 mm has significance increment in particle size, specific capacity, and lower the specific energy. The study by Ezurike *et al.*, 2018 results found to have for the ingredient milling machine with a capacity of 31 kg h^{-1} and 90% efficiency with 10% losses.

This study shows results, the variability (CV) of parameter effects for the average capacity of the respective ingredients has been for maize (3.72), wheat (6.49), and sorghum (4.46). The hammer mill has been tested with variable crops like maize, wheat, and sorghum with different sieve hole sizes (1 mm, 1.5 mm, and 2 mm). The machine was tested using 2 kg of dry maize, 2 kg of dry wheat, and 2 kg of dry sorghum at 13% moisture content for each sieve size with its respective replication, and the analysis was displayed in the above tables. From the results the average crushing efficiency, losses, and capacity of the machine were 93%, 7%, and 71.5 kg h^{-1} depending on the ingredient type and different size sieve holes. Generally, for all ingredient types as the sieve size increases, again the capacity and efficiency of the machine increases. With this, the maximum power and the speed of hammer mill have been 3 kW and 1800 rpm respectively.

CONCLUSION

This study was conducted to design a grain grinder machine and experiment test based on locally available materials. Based on the experimental testing results of milling, it can be concluded that:

i. The designed prototype machine was fabricated based on locally available materials.
ii. The designed hammer mill machine was tested for grains of fish feed like; sorghum, maize, and wheat with a readiness of moisture content of 13% for each ingredient.
iii. The maximum crushing efficiency (%) of maize, sorghum, and wheat was (94.5, 94, and 94) respectively at 1800 rpm hammer mill speed.
iv. The average capacity, time of milling, and the average coefficient of variation (CV) for maize, sorghum, and wheat were (3.72, 6.49, 4.46 and 3.61, 6.06, 4.69) % has been obtained respectively.
v. For the same weight (2 kg) of maize, sorghum, and wheat feed ingredients; time, capacity, and crushing efficiency were significantly affected by different sieve sizes.
vi. Due to different losses the mass of the ingredient reduces accordingly.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declare the contributions to the manuscript such as the following sections:
Maney Ayalew Desta: Design, methodology, writing orginal draft, review, and editing paper.
Ahmedie Oumer: Design, methodology, data collection during testing, and data analysis.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1133558

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 245-264

Research Article

Quality Evaluation of Foam Dried Watermelon Flakes

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ABSTRACT

Watermelon is mostly eaten in fresh form due to its high moisture content which is responsible for its deterioration within a short time. Foam-mat drying of watermelon was carried out using a mechanical dryer. In the foam mat drying experiments, 10% egg albumen and 2% carboxyl methylcellulose were used as the foaming agent and stabilizing agent, respectively. Thin layer drying was carried out in the mechanical dryer under temperatures of 60 and 70°C. Some nutritional qualities and chemical compositions of the watermelon were determined before and after drying. The result of the phytochemical properties revealed that the watermelon flakes have a high value of flavonoid content of 1.18±0.02 and 1.09±0.00 mg 100 g^{-1} with low terpenoid contents of 0.10±0.00 and 0.11±0.00 mg 100 g^{-1} for the sample dried using 60 and 70°C respectively. High ferric ion reducing antioxidant power (FRAP) value of 38.73±0.90 and 41.25±0.90 mg g^{-1} with low lycopene value of 0.312±0.00 and 0.323±0.01 mg g^{-1} was observed for the antioxidant properties of watermelon dried at 60 and 70ºC. The vitamin content shows that the flakes are highly rich in vitamin C (46.26±0.03 and 47.35±0.02 mg g^{-1} for 60 and 70°C, respectively) and had a low vitamin B_1 content (0.15±0.01 and 0.13±0.00 mg g^{-1} for drying temperature of 60 and 70°C, respectively). Therefore, the results of the foam-dried watermelon flakes showed that the qualities of the watermelon were preserved during drying and safe for consumption.

RESEARCH ARTICLE

Received: 21.06.2022
Accepted: 09.11.2022

Keywords:

- Watermelon,
- Nutritional qualities,
- Evaluation,
- Drying,
- Moisture content

To cite: Isa J, Olalusi AP and Omoba OS (2022). Quality Evaluation of Foam Dried Watermelon Flakes. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 245-264.* https://doi.org/10.46592/turkager.1133558

INTRODUCTION

Watermelon is produced all over the world during the warm season, mostly in areas with a lengthy growing season (Snowdon, 1990). Watermelon (*Citrullus lanatus*) is a member of the cucurbitaceous family, according to Simmond *et al.* (1976), and is thought to have originated in the arid regions of Southern Africa. Watermelon is most known for its crisp, juicy, and refreshing pulp, which is eaten as a snack. Watermelon is a good source of fluids in Africa's dry regions (Tindall, 1991). Watermelon (*Citrullus lanatus*) was also described by Robinson and Decker-Walters (1997) and Jeffrey (2001) as a significant horticultural crop, primarily renowned due to its sweet and juicy nature. According to FAOSTAT (2008), out of the total area devoted to vegetation production in African in 2008, watermelon covers about 54% and this is 4.6% of 199.194 million tons of world production of watermelon. Watermelon contains a large number of the carotenoids, and its red flesh was regarded as a reliable source of lycopene as reported by Figueroa *et al.* (2012), who also reported the probability of consumption of watermelon to be antihypertensive. Watermelon has some other important values such as the vitamins, high moisture, and trace of cholesterol, therefore, it is consumed for its therapeutic value, which includes thirst-quenching and anti-inflammatory compounds. Which is the major cause of asthma, atherosclerosis, diabetes, colon cancer and arthritis (Sundia, 2007) and (Isa and Olalusi, 2019).

Alam (2013) reported that watermelon is one of the under-utilized fruit majorities grown in the tropical part of the world despite its nutritional value. Watermelon has a layer of white-fleshed internal ring and interior or edible flesh with high variability in thickness based on their maturity and size and the major problem of this crop include its high perishability. Several researchers such as Johnson *et al.* (2013), Oseni and Okoye (2013), Parmar and Kar (2009), Lakshmi and Kaul (2011), Fila *et al.* (2013), Gin *et al.* (2014), Egbuonu (2015), Adedeji (2017), Isa and Olalusi (2019), Munawar *et al.* (2020) have reported some properties of the fresh watermelon but less information is available on the compositional properties for both the fresh watermelon and its flakes.

The process of eliminating or lowering moisture from an agricultural product in order to improve its characteristics and attributes is known as drying. However, Foam mat drying, on the other hand, is a method for drying in which a liquid or semi-liquid concentration of agricultural material is whipped into a foam-like substance and then dried by exposing the product to hot air in a thin layer. Foam mat drying is a type of drying in which a concentration of agricultural material in a liquid or semi-liquid condition is whipped to create a foam-like substance and then dried by exposing the product to hot air in a thin layer. Morgan *et al.* (1961) developed the first foam mat drying process, after which several researchers report the further process and application (Ginnette *et al.*, 1963; Hart *et al.*, 1963; Berry *et al.*, 1972; Berry *et al.*, 1965). The foam mat method was a good process of dehydrating temperature-sensitive food material with great advantage in the reconstitution of the dried product and energy-saving by shorting the drying time. Jagtiani *et al.* (1998) reported that the drying temperature for a foam mat drying process range between 50°C and 70°C. Javed *et al.* (2018) also, reported the increasing surface area as a factor that accelerates the drying process as it enhances the moisture removal, therefore, foam mat drying of liquid and semiliquid food and make them into foam, based on the liquid level the addition of foaming and the stabilizing agent makes the dried product easily convertible to powder. However, this study aims at the quality evaluation of watermelon puree before and after the foam mat drying process in a mechanical dryer.

MATERIALS and METHODS

Preparation and collection of samples: watermelon sample (sugar baby varieties) was obtained from Oja Oba market in Akure south local government of Ondo State, Nigeria. Prior to the commencement of the drying experiment, the flesh was pulped and homogenized using a home mixer after the rind was separated from the flesh and the seeds were removed. An electric blender (Orpat-HHB100E, Ajanta Limited, India) was used to whip a known-weight sample size at 1800 rpm. On a wet juice weight basis, the foaming ingredient is egg albumen (10%) with food-grade methylcellulose (stabilizing agent) at 2%. During the whipping process, egg albumen and methylcellulose were added to foam and stabilize the watermelon juice (Javed *et al.*, 2018).

Foam-mat drying experiment

A mechanical drier with a heating chamber, air blower, drying air outlet holes, and temperature regulator was employed for the drying of the foamed watermelon pulp in a food-grade stainless steel tray. The drier was turned on for a while to keep the chamber at the correct temperature. The homogenous foamed watermelon pulp was dried at constant air velocity (1.0 m s^{-1}) under 60 and 70°C. The foam-mat was peeled and packed for further investigations and analysis when it had dried to the point where the weights of the samples recorded had become consistent values.

Important drying parameters

Moisture ratio: Equation 1 express the moisture ratio based on the moisture content during drying:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

Because the M_e value is so little in comparison to the M_o and M_t, it was ignored, and the moisture ratio may be written as shown in Equation 2

$$MR = M_t/M_o \tag{2}$$

Where M_t is the moisture content in a time (%), M_e is the moisture content at equilibrium in (%), and M_o is the initial moisture content in (%), and MR is the dimensionless moisture ratio.

Moisture content: The amount of moisture in a substance can be stated as a decimal or a percentage, and it can be expressed wet or dry. The moisture content on a wet basis is the weight of moisture in a product per unit weight of undried material, denoted as shown in Equation 3.

$$Mwb = \frac{wo - wd}{wo} * 100 \tag{3}$$

W_0 is wet sample's starting weight, W_d is the sample's dried weight, M_{wb} is the sample's moisture content on a wet basis, and M_{db} is the sample's moisture content on a dry basis.
Drying rates: Agricultural products differ from most other materials that are frequently dried, such as laundry, sand, stone, dust, or paper. Agricultural things (which are hygroscopic) normally retain some moisture after drying, but non-hygroscopic materials can be dried entirely. Due to hygroscopic substances, moisture is trapped in constricted capillaries. The rate of moisture flow is only approximately proportional to the vapour pressure differential with the environment due to the crop's resistance to moisture flow. As a result, Equation 4 was used to compute the drying rate of the foam dried product:

$$Drying\ rate\ = \frac{M_{t+dt} - M_t}{dt} \tag{4}$$

Proximate analysis
Standard analytical techniques were used to determine the proximate components (AOAC, 1995) of the fresh and dried watermelon flakes.

Moisture content determination: The moisture content of the sample was determined using the AOAC method. In the oven, the Petri-dish was properly cleaned and dried. 100 g of the material was then placed in a pre-weighed Petri plate and dried at 105°C for two hours. The dish and dry sample were moved to the desiccator to cool to room temperature before being weighed again.

Ash content determination: The inorganic residue left after the sample's organic substance has been destroyed is represented by the ash content of the material. For 4-6 hours, keep the silica dish in the Muffle furnace at no more than 525-550°C. Calculate the percent ash by weighing the ash and using the calculation provided in the standard procedure. In a muffle furnace, about 5 g of the material was weighed into a crucible and cooked for 6 h at 500°C until it turned grey ash or white. The plate was withdrawn from the muffle furnace and placed in the desiccator to cool using crucible tong. It was re-weighed when it cooled, and the difference was used to compute the ash weight. The ash content was determined using the method described by AOAC (1995) as shown in Equation 5

$$\%\ ash\ content = \frac{weight\ of\ ash}{weight\ of\ sample} \times 100 \tag{5}$$

Fat content determination: The soxhlet fat extraction technique AOAC (1995) was used to calculate fat content. A 250 mL boiling flask was completely cleaned and dried in a 105°C oven for 30 minutes before cooling in a desiccator. Following that, the dried sample was accurately weighed into labelled thimbles, yielding a total weight of 2 g. In a cooled boiling flask, 200 mL petroleum ether was heated to 40-60°C. After the extraction thimble was gently blocked and the boiling flask containing the petroleum ether was allowed to boil in the extraction thimble, the Soxhlet apparatus was allowed to reflux for 6 h. The flask was withdrawn after it was clean of petroleum ether and heated for 1 h at 105°C. It was moved from the oven to the desiccator to cool before weighing.

$$\% \, fat \, content = \frac{weight \, of \, ether \, soluble \, material}{weight \, of \, sample} \times 100 \qquad (6)$$

Fibre content determination: The crude fibre was an organic residue that remained after the food sample was treated under controlled conditions with conventional hot acid and alkali solutions. In a 250 mL conical flask, 2 g of the sample was weighed, 200 mL of 1.25 percent H_2SO_4 was added, and the mixture was heated under reflux for 30 minutes. The solution was filtered through Whatmann filter paper and washed with hot water until it was no longer acidic, as shown by the pH paper. The residue was transferred to a 250 mL beaker, and 200 mL of 1.25 percent NaOH was added.

After boiling for 30 minutes in a digestion apparatus, the mixture was filtered and washed with distilled water until the filtrate was pH paper neutral. The residue was transferred to the crucible and dried in an electric oven for 8 hours at 100°C. After that, it was removed and placed in a desiccator to cool before being weighed. The material was weighed first, then burned, desiccated, then weighed once more. The crude fibre content was calculated as follow:

$$\% \, Crude \, fibre = \frac{fibre \, weight}{weight \, of \, sample} \times 100 \qquad (7)$$

Protein content determination: The Kjeldahl method was used to determine the sample's composition. To calculate the protein content, total nitrogen was multiplied by a conversion factor of 6.25. A selenium catalyst was introduced to a Kjeldal digestion flask containing 0.5 g of the sample. The flask was filled with just 20 mL of H_2SO_4, 10 g of Na_2SO_4, and 1 g of $CuSO_4$, and the solution was digested by heating in a fume cupboard until it was completely digested and became blue. The titration solution was removed and used with caution. When colour of the distillate reverted to the light pink hue of the boric acid and screen methyl red indicator combination, the titration was completed.

Carbohydrate determination: Using the arithmetic difference approach, the carbohydrate content of the test sample was calculated.

$$\% \, CHO \; = \; 100 - (\, \% \, fat. + \% \, ash \; + \; \% fiber + \% protein \,) \qquad (8)$$

Analysis of phytochemicals

Alkaloid determination: On a steam water bath, 0.5 g of the extract was agitated in 5 ml of 1% aqueous HCl, 1 ml of the filtrate was treated with a few drops of Dragendorf reagent, and blue-black turbidity was obtained as early evidence for the presence of alkaloid.

Saponin determination: The content was determined using a screening technique based on the stability of saponin to created foam in an aqueous solution. 0.5 g of extract shaken with distilled water in a test tube foaming that persists after warming was employed as a preliminary confirmation for the presence of saponin. Brunner's spectrophotometric approach was used to determine saponin content (Brunner, 1984). In a 250 mL beaker, 2 g of finely powdered material was weighed, and 100 mL of isobutyl was added. To ensure even mixing, the mixture was shaken for 5 hours. Using No. 1 Whatman filter paper, the mixture was filtered into a 100 mL beaker containing 20 mL of a saturated 40% magnesium carbonate solution ($MgCO_3$). To achieve a clear colorless solution, the combination is filtered once more using No 1 Whatman paper. Using pipette, 1 mL of the colourless solution was transferred to a 50 mL volumetric flask, which was then filled to the mark with 2 mL of 5 percent iron (iii) chloride ($FeCl_3$) solution and distilled water. It was left for 30 minutes to allow the colour to develop. The absorbance was compared to a blank at 380 nm.

Tannin content determination:
A black green precipitate was generated by combining 0.5 g of the extract with 100 ml of distilled water, filtering the filtrate, and adding ferric chloride reagent to the filtrate. In a 50 ml sample container, 0.2 g of finely powdered material was weighed. A total of 10 mL of 70% aqueous at 30°C in an ice bath shaker. The supernatant from each solution was frozen after centrifugation.

0.2 ml of each solution was pipetted into the test tube, then add 0.8 ml of pure water. 0.5 mg ml^{-1} of stock and 1 mL purified water were used to make standard tannic acid solutions. Both the standard and the sample received 0.5 mL of Folinciocateau reagent, followed by 2.5 mL of 20 percent Na_2CO_3. After vortexed and incubated for 40 minutes at room temperature, the absorbance was measured at 725 nm against a reagent blank concentration of the same solution from a standard tannic acid curve (Makkar, 1996).

Determination of flavonoid content: 1 mL aqueous extract was combined with 1 mL lead acetate solution (10%). The presence of a yellow precipitate was defined as a positive test for flavonoids (Njoku and Obi, 2009). A 0.5 g extract was treated with 20 mL of mild ammonia solution. The yellow colour was erased with the addition of mL conc. H_2SO_4, suggesting the presence of flavonoids.

Determination of steroid content: Add 10 mL chloroform to 200 mg plant extract. 2 mL of this filtrate, 2 mL acetic anhydride, and 2 mL conc. H_2SO_4 steroids are shown by the blue green ring (Siddiqui *et al.*, 2010). In each extract of 0.5 g, 2 mL of acetic anhydride and 2 ml of H_2SO_4 were added. The presence of steroids was indicated by the change in hue of several samples from violet to blue or green (Egwaikhide and Gimba, 2007).

Determination of terpenoid: 3 mL of the concentration was filtered after 0.5 g of the extract was mixed with 20 mL of chloroform H_2SO_4 was added to the filterate to create a layer. Near the touch, a reddish-brown tint was seen, suggesting the presence of terpenoid. According to Sofowora (1993), a technique was used. 0.5g of finely powdered material was weighed into a 50 mL conical flask, and 20 mL of chloroform methanol 2:1 was added. The mixture was properly mixed before being placed aside for 15 minutes at room temperature. The suspension was centrifuged at 3000 rpm, the supernatant was discarded, and the precipitate was washed twice with 20 ml chloroform: methanol 2:1 and centrifuged before being dissolved in 40 ml of 10% SDS solution. Before measuring absorbance at 510 nm, 1 ml of 0.01 M ferric chloride was added and left for 30 minutes.

Determination of antioxidant properties:

Determination of antioxidant properties: Sadler *et al.* (1990) described a modified version of their technique, which was reported by Ambreen *et al.* (2013) was used in this study.

The lycopene content was determined using a modified version of the method described by Sadler *et al.* (1990). About 0.6 g of material was mixed with 5 ml of acetone containing 0.05 percent (w/v) BHT, 5 ml of 95 percent ethanol, and 10ml of hexane. The homogenate was centrifuged for 15 minutes at 400 g at 4°C. Three milliliters of distilled water were then added. To aid phase separation, the vials were shaken for 5 minutes and then stored at room temperature. A spectrophotometer was used to measure the absorbance of the top hexane layer in a 1cm-pathlength quartz cuvette at 503 nm.

Hexane was used as the blank and the Ambreen *et al.* (2013) approach was used to assess total phenol, ferric reducing antioxidant power (FRAP), and 2.2-diphenyl-1-picrylhydrazyl (DPPH). Arunachalam *et al.* (2014) used the technique described by Arunachalam *et al.*, (2014) to assess the amount of 2,2-azinobis (3-ethyl benzothiazoline)-6-sulfonic acid (ABTS), -carotene, and lycopene. The following equation was used to calculate the sample's lycopene content:

$$ycopene \left(\frac{mg}{kgoftissue}\right) = \frac{A_{503} \times 31.2}{MassofTissue\ (g)} \qquad (9)$$

Where A503 is the absorbance of the upper hexane layer.

Data analysis

The data for each treatment: Fresh and foam dried watermelon (60 and 70°C) were repeated in triplicate. The quality parameters were visualized using bar chart on MS excel version 2016. The treatments were compared using mean comparison (Tukey test) at 0.05 probability level on XLSTAT version 2018.

RESULTS AND DISCUSSION

Drying curve

Figure 1 shows the moisture profile of the foam dried watermelon as a function of drying time at two different temperatures (60 and 70°C). The figure shows that the moisture content obtained for the final products of watermelon puree reduces with 74.81 and 81.04% for the drying temperature of 60°C and 70°C, respectively. However, the foam mat drying process of watermelon (using 10% egg albumen and 2.0% CMC) was found to be affected by increase in temperature, as increase in temperature increases the specific amount of moisture removed from the sample and reduces the required drying time for complete drying process Franco *et al.* (2015) found a similar conclusion in his research of the influence of process factors on yacon foam mat drying kinetics (*Smallanthus sonchifolius*), Noordia *et al.* (2020) also arrive on the same conclusion in his research on foam mat drying of banana juice.

The moisture drying rate pattern during the drying process of the foam dried watermelon (10% egg albumen and 2.0 percentage of CMC) at two different drying temperatures show a similar trend but different magnitude. the rate of drying of the foamed watermelon increase with increase in the temperature as shown in Figure 2 where the drying rate was calculated as a function of drying time and moisture content. However, no consistent drying rate period was seen in the drying curves for this investigation at any drying setting. After an initial fast rise, the drying rate falls constantly with time and with decreasing moisture content, and the whole process occurred throughout the falling rate phase. This finding is consistent with the findings of Togrul and Pehlivan (2004), Akpinar *et al.* (2006), Shivani *et al.*, (2019).

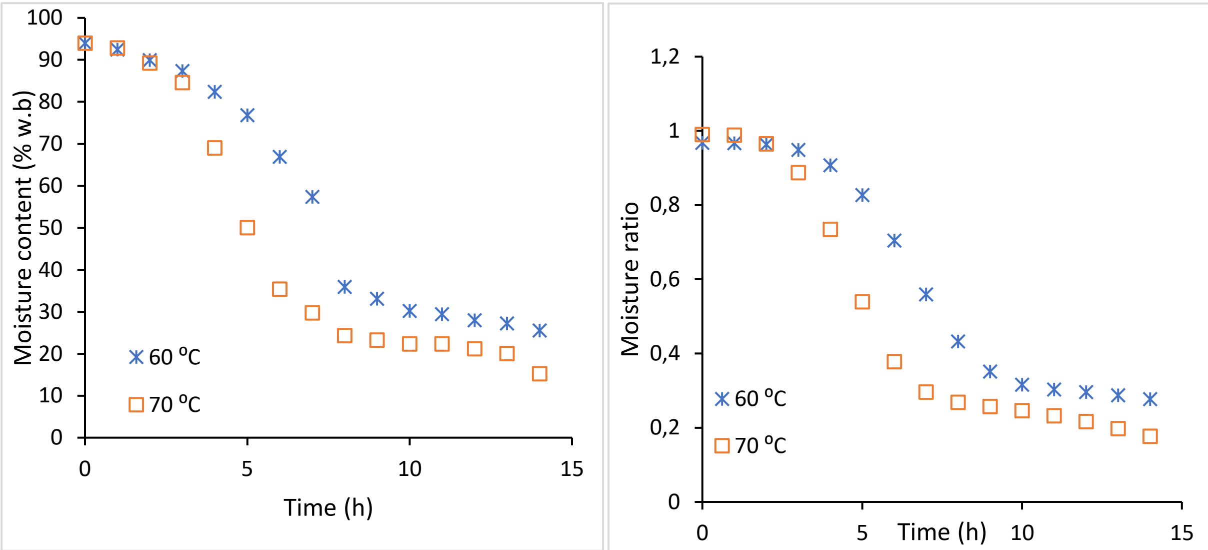

Figure 1. Moisture content and moisture ratio vs drying time.

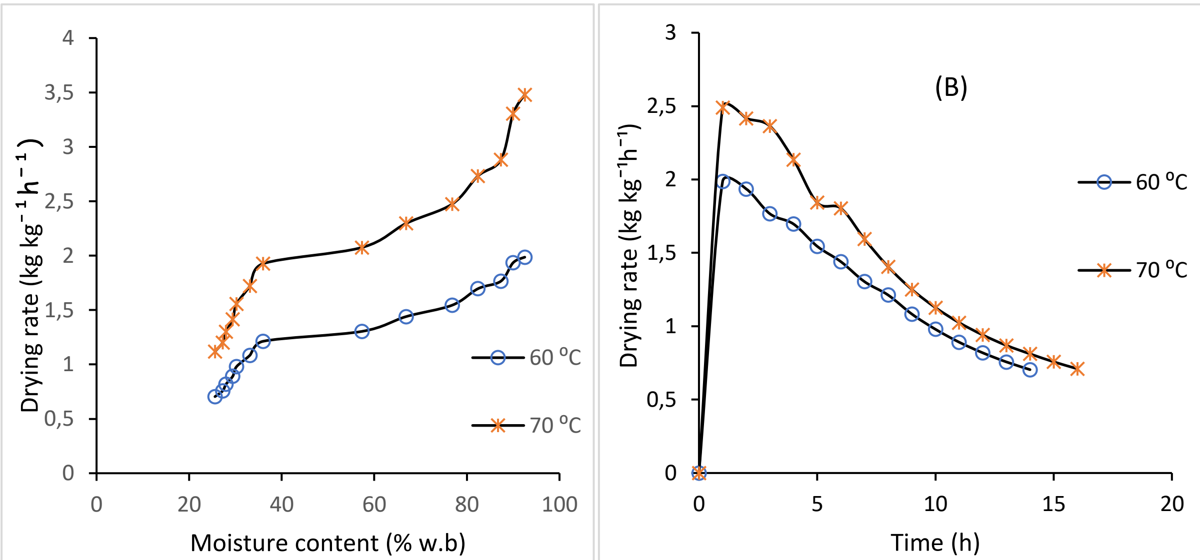

Figure 2. Drying rate *Vs* (A) moisture content and (B) drying time under different temperature.

Nutritional composition of watermelon

Proximate composition: The moisture, ash fat, fibre, protein and carbohydrate (CHO) content of fresh watermelon flesh were 90.03±0.38, 5.20±0.40, 0.19±0.01, 0.20±0.05, 1.05 and 3.32±0.40% with energy of 21.08±1.63 kcal 100 g^{-1}. The result of the proximate composition of foam dried watermelon flakes at different temperature (60°C and 70°C) in comparison with the proximate composition of the fresh sample is presented in Figure 3. The composition includes moisture (3.980.02; 4.440.014), ash (5.650.011; 11.850.0008), fat (4.060.063; 4.12 0.007), fibre (1.060.001; 1.120.000), protein (3.510.014, 3.280.035) and CHO (81.740.057%, 75.20.019%) of the foam dried watermelon at different temperature (60°C; 70°C, respectively). The results of the proximate analysis in this study were similar to those published by Ambreen *et al.* (2013) who reported the moisture, protein, fat, ash and nitrogen-free-extract (NFE) and CHO content of fresh watermelon as 92.02±1.65, 0.49±0.02, 0.11±0.001, 0.32±0.06, 0.27±0.03 and 6.79±0.25%, respectively and According to Inuwa *et al.* (2011), the moisture, ash, protein, fat, and fiber content of fresh watermelon ranged from 93.40 to 94.60%, 0.50 to 0.60%, 0.10 to 0.15 percent, 0.30 to 0.40%, and 0.50 to 0.55%, respectively. The small changes in watermelon content might be attributed to varietal differences (Yau *et al.*, 2010), harvesting period or season (Arocho *et al.*, 2012) and flesh crispness (Shofian *et al.*, 2011) of the fresh watermelon. The current results are likewise consistent with the USDA (2010) that published the values for the proximate composition of watermelon as 91.45 g moisture in 100 g sample of watermelon and the remaining characteristics like protein, fat, ash, and dietary fiber as 0.61, 0.15, 0.25, and 0.40 g 100 g^{-1}. Nevertheless, for the foam dried watermelon flake, the low moisture content implies that there will be an increase in the lifespan of the foam dried watermelon concentrates as it is significantly lower than that of the fresh sample. The ash content of the sample dried at 70°C in this study is significantly higher ($P<0.05$) than that of 60°C, which is not statistically different from the fresh sample. The value published by Inuwa *et al.* (2011), and the high ash content in the sample shows the percentages of inorganic mineral elements contained in watermelon flakes, and high mineral elements in foods improve growth, development and also accelerate metabolic processes in the human body. The fat and fiber content of the foam dried watermelon produced in this investigation is greater than the results reported by Ambreen *et al.* (2013). This study's fiber content ranged between 1.06 and 1.12%, which was greater than the results of Ambreen *et al.* (2013) and Inuwa *et al.* (2011). Fiber is thought to lower the level of cholesterol in human blood, as well as the risk of certain malignancies. The watermelon flakes had a high carbohydrate content, suggesting that they may also be used as a source of carbohydrate, while the protein level was greater when compared to the results of Ambreen *et al.* (2013) and Inuwa *et al.* (2011).

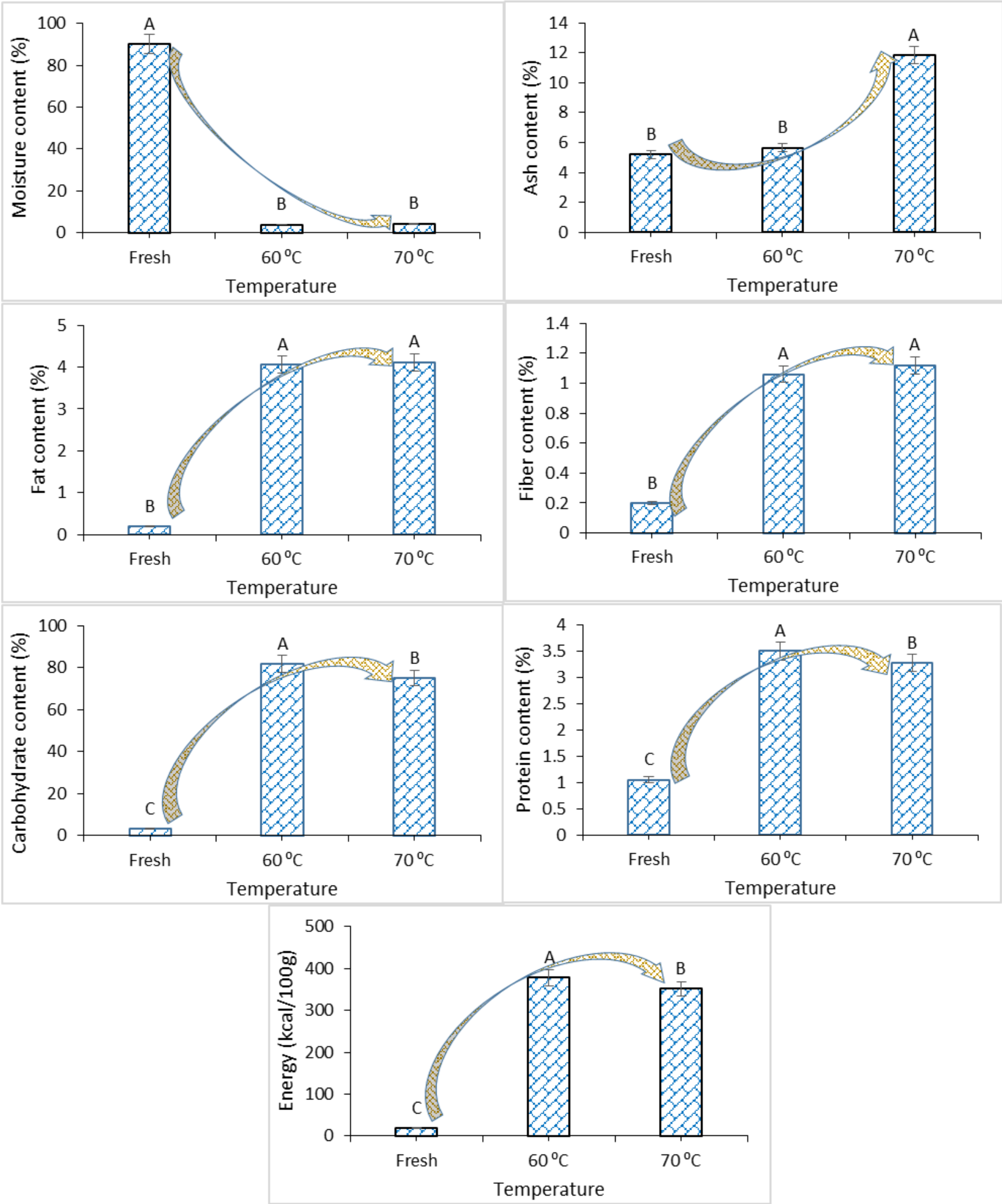

Figure 3. Proximate composition of fresh and dried watermelon: the column shows the magnitude of the content; the error bar denotes the standard deviation; the arrow shows the increment or decrement and bar with the same alphabet are not significantly different (P<0.05).

Mineral content of watermelon

Figure 4 depicts the mineral compositions of fresh and foam-dried watermelon. The figure shows the presence of K, Na, Fe, Mg, and Cu in the pulp is 173±5.0, 1.5±0.04, 0.4±0.01, 15.4±0.25 and 0.1±0.003 mg 100g^{-1} respectively in fresh watermelon. The mineral content (mg 100 g^{-1}) of foam dried watermelon flakes showed the presence of K (53, 46), Na (8.6, 5.2), Fe (0.15, 0.18), Mg (264, 271), Cu (142, 153,) and Na: K (0.37, 0.30) at the temperature of 60°C and 70°C, respectively.

The result for the fresh watermelon agrees with the value reported by Ambreen et al. (2013) on watermelon juice were 126±2.36, 0.81±0.03, 0.26±0.01 and 0.031±0.001 mg 100 g^{-1} were reported for K, Ca, Na, Fe, and Zn respectively and Nagaski (2006) reported, Na, K, Ca, and Fe had concentrations of 60 mg 100 g^{-1}, 2 mg 100 g^{-1}, 145 mg 100 g^{-1}, and 24 mg 100 g^{-1}, respectively, which are greater than the results of this study,

Inuwa *et al.* (2011) found that the iron level of watermelon varied from 0.18 to 0.33 mg 100 g^{-1}. Furthermore, Proietti *et al.* (2008) reported 154 mg 100 g^{-1} potassium in watermelon. According to Colla *et al.* (2006), potassium concentrations varied from 107 to 114 mg 100 g^{-1}, with Na, Ca, and Mn concentrations of 0.70, 6.40, and 0.027 mg 100 g^{-1}, respectively. The variation in agronomic techniques, geographical circumstances, ripening stage, and harvesting season ripening stage, and harvesting season might all have an impact on the mineral content of fresh watermelon in this study. The minerals contained are extremely beneficial to the body's health. Nonetheless, the magnesium and potassium content of the foam dried sample is lower than that of the fresh sample, but the magnesium content is unaffected by changes in the system's temperature.

Except for the potassium content in the foam dried watermelon, which increases significantly with increased system temperature, all other minerals selected for this study show that their composition in the foam dried watermelon is significantly higher than the fresh watermelon at ($P<0.05$) and their values significantly decrease with increased system drying air temperature, with the exception of the potassium content in the foam dried watermelon. This research, however, has a high iron content, which aids in the production of blood and the transfer of O_2 to CO_2 from one tissue to another. In children, iron deficiency causes academic difficulties and behavioral issues, as well as anemia. Furthermore, the potassium content reported by ranges from 107 to 114 mg 100 g^{-1} which was low when compared with the result of this study. People who take diuretics to manage and suffer from excessive potassium excretion through the bodily fluids benefit from high potassium because it promotes iron consumption. Potassium may be found in a variety food, including fruits, dairy products, and vegetables. And it has a daily consumption recommendation of 3500 mg. The obtained result, Na, 0.70 mg 100 g^{-1}, is close to the suggested threshold. This is a modest number when compared to the experiment's outcome. Sodium helps muscles and neurons function properly by regulating fluid equilibrium in the body. The daily sodium requirement for adults and children aged 4 and others 2400 mg. However, because the sodium-potassium ratio (Na/K, 0.30 to 0.37 mg g^{-1}) is less than 1, the foam dried watermelon is safe for hypertension patients to consume (Ambreen *et al.*, 2013; Inuwa *et al.*, 2011; Proietti *et al.*, 2008; Nagaski, 2006; Adedeji, 2017).

Vitamin content of the watermelon

Foam dried watermelon flakes of different temperatures (60°C and 70°C) were investigated for their vitamin content and the results are presented in Figure 5. It was observed that Retimol (VA), Thiamine (VB_1), Riboflavin (VB_2), Niacin (VB_3), Pyridoxine (VB_6), B_{12} and Ascorbic acid (VC) content of fresh watermelon are 693.43±18.61 mg ml^{-1}, 3.25mg g^{-1}, 0.137±0.176mg g^{-1}, 0.233±0.012 mg g^{-1}, 0.117±0.006mg g^{-1}, 0.006±0.001mg g^{-1} and 11.747±0.211 mg 100 g^{-1} respectively. The vitamin content (mg g^{-1}) includes: VA (17.34±0.184, 13.24±0.028), VB_1 (0.14±0.003;

0.13±0.001), VB_2 (0.15±0.001; 0.96±0.004), VB_3 (1.66±0.002, 1.12±0.001,), VB_6 (0.50±0.002; 0.53±0.003), VB_{12} (0.77±0.001; 0.81±0.006), and VC (46.26±0.028; 47.35±0.021) at the temperature of 60ºC and 70ºC, respectively. The result reveals the presence of vitamin C and A at a very high quantity, the vitamin content is found higher when subjected to a high drying temperature of 70°C. Vitamin B_1 and B_2 were found in a close range (0.1-1.00) for both temperatures selected for this study. B and C vitamins are known to be water-soluble and heat-labile, which might explain why they are being depleted. The vitamin A, B_6, and C levels found in fresh watermelon are identical to those found in a paper by USDA (2010). However, the result shows that Vitamin A and B_1 content of the foam dried sample is lower compared to the fresh sample but the value obtained under the two temperatures of the system has no significant ($P>0.05$) difference for Vitamin A. The Vitamin B_1 content of the foam dried watermelon decreases significantly ($P<0.05$) with increased system temperature, whereas all other selected vitamins in this study show that the vitamin content in the foam dried watermelon is significantly ($P<0.05$) higher than fresh watermelon and the value significantly increases with increased dryer drying air temperature. Except for the Vitamin B_3 content, which decreases significantly ($P<0.05$) with increased dryer drying air temperature.

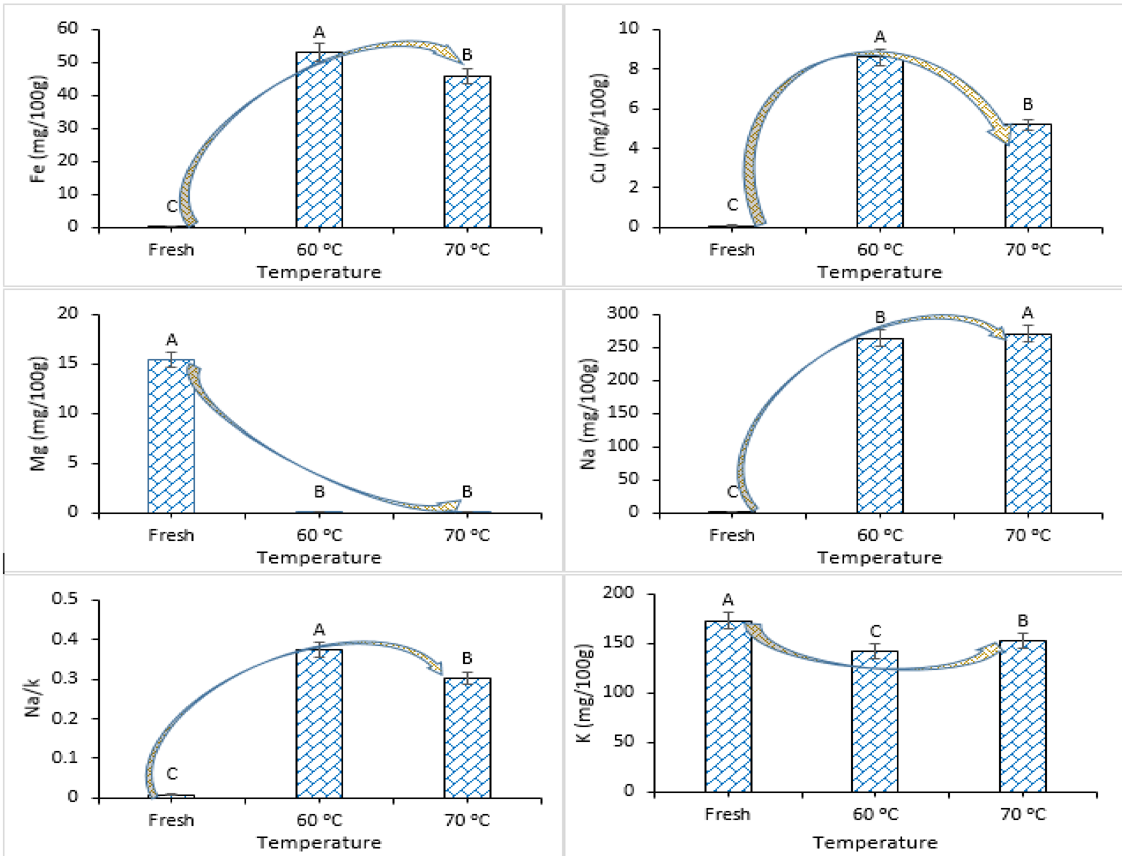

Figure 4. The mineral composition of fresh and dried watermelon the column shows the magnitude of the content; the error bar denotes the standard deviation; the arrow shows the increment or decrement and bar with the same alphabet are not significantly different ($P<0.05$).

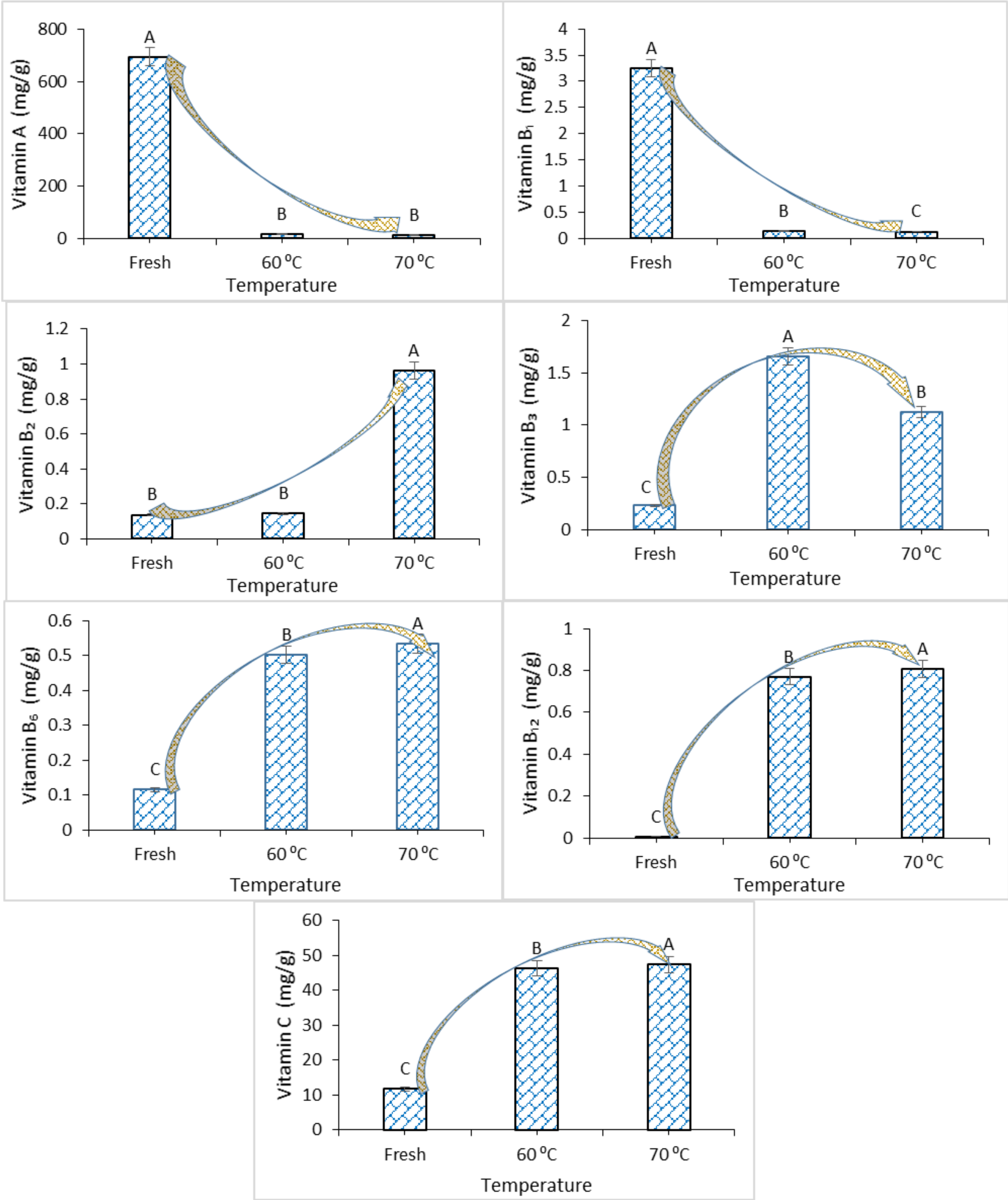

Figure 5. Vitamin composition of fresh and foam dried watermelon; the column shows the magnitude of the content; the error bar denotes the standard deviation; the arrow shows the increment or decrement and bar with the same alphabet are not significantly different (P<0.05).

Antinutritional composition of watermelon

Phytochemical composition: The knowledge of phytochemical composition in food offers understanding of the food's pharmacologic, nutritional, and hazardous potential flavonoid, saponins, alkaloids, and tannins (Figure 6). The flavonoid concentration in the pulp (2.40±0.1%) was lower compared to the range 36.8±120 – 39.6±0.02 mg 100 g^{-1} in *Solanum incanum* (Auta *et al*., 2011), but in agreement with the value (2.15±0.05) reported for roasted dehulled *Trculia Afreicana* (Ijeh *et al*., 2010). Because the flavonoid contains antifungal and antibacterial characteristics, their presence in the samples implies that their usage might protect against diseases caused by free radicals, bacteria, and fungi (Adeolu and Enesi, 2013). Saponins have a bitter taste that may be linked to pharmacologic properties such as hemolytic activity (Sodipo *et al.*, 2000). Adeolu and Enesi (2013) and Chaux-Gutiérrez *et al.* (2017) report positive benefits on blood cholesterol levels, bone health, cancer, and immune system activation. Alkaloids (low concentration) are therapeutically useful natural plant chemicals because of their analgesic, antispasmodic, and antibacterial properties (Adeolu and Enesi, 2013). The pulp's alkaloid concentration (0.040.03%) is lower than the range seen in *Treculia Africana* seeds (0.350.05 to 0.580.08%) (Ijeh *et al.*, 2010).

The tannin concentration of the pulp (1.33±0.03%) is higher than that of sweet potatoes leaves (0.21±0.02) by Antia *et al.* (2006), but lower than that of *Treculia Africana* seeds (Ijeh *et al.*, 2010). Also, the values given by Egbuonu (2015) for watermelon are extremely comparable. The watermelon pulp flavonoid concentration (2.40±0.1%) is lesser than the flavonoid content (36.8±1.20-39.6±0.02 mg 100 g^{-1}) of raw and processed *Solanium Incanum* (Auta *et al.*, 2011).

Because the flavonoids contain antifungal and antibacterial characteristics, their presence in the samples implies that their usage might protect against diseases caused by free radicals, bacteria, and fungi (Adetola and Enesi, 2013). The identification of tannins in particular suggested the product might contains astringents and antimicrobials (Adeoju and Enesi, 2013) and could be used to trat a variety of ailments, such as inflammation, kidney failure, liver problems, hypertension and reactive oxygen species inhibition (Zhu *et al.*, 1997; Cakmak, 2020).

However, the phytochemical properties of foam dried watermelon flakes are presented in Figure 6. The alkaloid, tannin, flavonoid, steroid, saponin and terpenoid contents were 0.45±0.014, 0.34±0.021, 1.18±0.021, 0.82±0.001, 1.07±0.021, 0.10±0.004 mg g^{-1} respectively at drying air temperature of 60°C and 0.39±0.007, 0.32±0.014, 1.09±0.007, 0.88±0.001, 1.03±0.021, 0.11±0.002 mg g^{-1} respectively at temperature 70°C. Johnson *et al.* (2013) reported similar results for dried watermelon where, saponin, alkaloid, tannin, phytate, flavonoid, oxalate and phenol contents were obtained as 3.08±0.05, 0.35±0.00, 0.18±0.01, 0.10±0.01, 3.20±0.10, 0.03±0.0001, 0.06±0.0001 mg g^{-1}, respectively. Also, the alkaloid content is very close to the result of 0.35±0.05-0.58±0.08% for *Treculia africana* seeds (0.35±0.05 to 0.58±0.08%) reported for *Treculia africana* seeds (Ijeh *et al.*, 2010). The tannin content is significantly larger than the value (0.21±0.02 mg 100 g^{-1}) for sweet potato leave (Antia *et al.*, 2006). The saponin content gotten in this study is lesser than the 6.0±0.06 mg 100 g^{-1} of *Punicagranatum*'s saponins (Dangogo *et al.*, 2011) and 18.7±0.31-19.9±0.67 mg 100 g^{-1} of *Solanumincanum (Auta et al., 2011).* Although, the values (0.13±0.03-0.37±0.03) reported for *Treculia africana* (Ijeh *et al.*, 2010) is was greater, however, the result shows that the foam dried watermelon flake has a very high flavonoid content for both temperatures than other phytochemical content (alkaloid, steroids, terpenoid, saponin, and tannins) considered in this study.

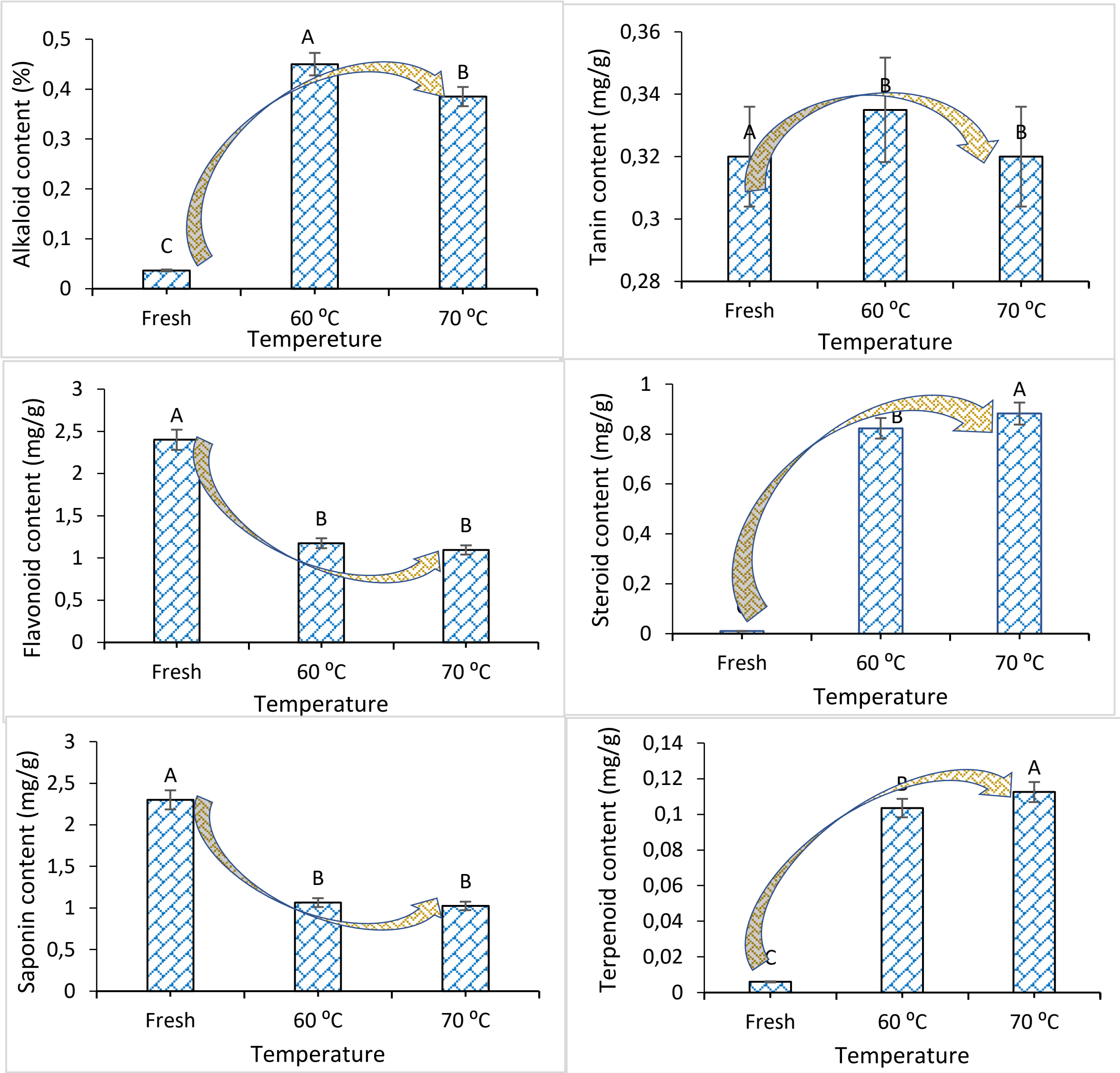

Figure 6. Phytochemical properties of fresh and dried watermelon: the column shows the magnitude of the content; the error bar denotes the standard deviation; the arrow shows the increment or decrement and bar with the same alphabet are not significantly different (P<0.05).

Antioxidant properties of watermelon

The antioxidant properties of fresh and foam-dried watermelon flakes at different temperature of 60 and 70°C was examined, and the result is sown in Figure 7. The result shows that β-carotene(mg g^{-1}), lycopene(mg g^{-1}), total phenol (mgGAE g^{-1}), ABTS (ulEAC g-1), FRAP (mgAAE g^{-1}) and DPPH(%) were 1.30±0.00, 5.42±0.00 6.71±0.01, 20.17±0.24, 36.10±0.75, and 56±0.47 respectively for fresh watermelon, 9.55±0.007, 3.12±0.007, 8.57±0.47, 22.44±2.31, 38.73±0.90 and 54.22±1.12 respectively for temperature of 60°C and 8.77±0.007, 3.23±0.014, 8.76±0.47, 15.7±2.31, 41.25±0.90 and 54.01±1.12 mg g^{-1} respectively for temperature of 70°C (Barba *et al.*, 2006), computed lycopene in various fruits and vegetables. They concluded that watermelon and tomatoes had the highest lycopene content. Charoensiri *et al.* (2009) looked at 37 different fruits and found red watermelon to be one of the best suppliers of lycopene. Perkins-Veazie *et al.* (2006) examined 50 different watermelon cultivars and found lycopene levels ranging from 3.52±2.30 to 11.20±2.0 mg 100 g^{-1}. Katherine *et al.* (2008) extracted 3.70 mg 100 g^{-1} of lycopene at 60°C and found a steady reduction when the extraction temperature was increased up to 75°C. Other researcher also concluded that watermelon is a good source of lycopene (Oms-Oliu *et al.*, 2009; Liu *et al.*, 2012; Ambreen *et al.*, 2013). According to Johnson *et al.* (2013), the flesh of *Citrullus lanatus* is a good source of carotenoid (lycopene and carotene (pro-vitamin A)). However, - carotene in watermelon is considerably less abundant than lycopene. The level of β-carotene in watermelon flakes, on the other hand, is larger than the content of lycopene, according to the findings of this study. When dried with a constant drying temperature. β- Carotene which is another important carotenoid in watermelon is much lower in quantity compared to lycopene. According to Setiawan *et al.* (2001) the fresh flesh Citrullus lanatus is a good source of carotenoid, lycopene, and beta-carotene (provitamin A) (Liu *et al.*, 2012).

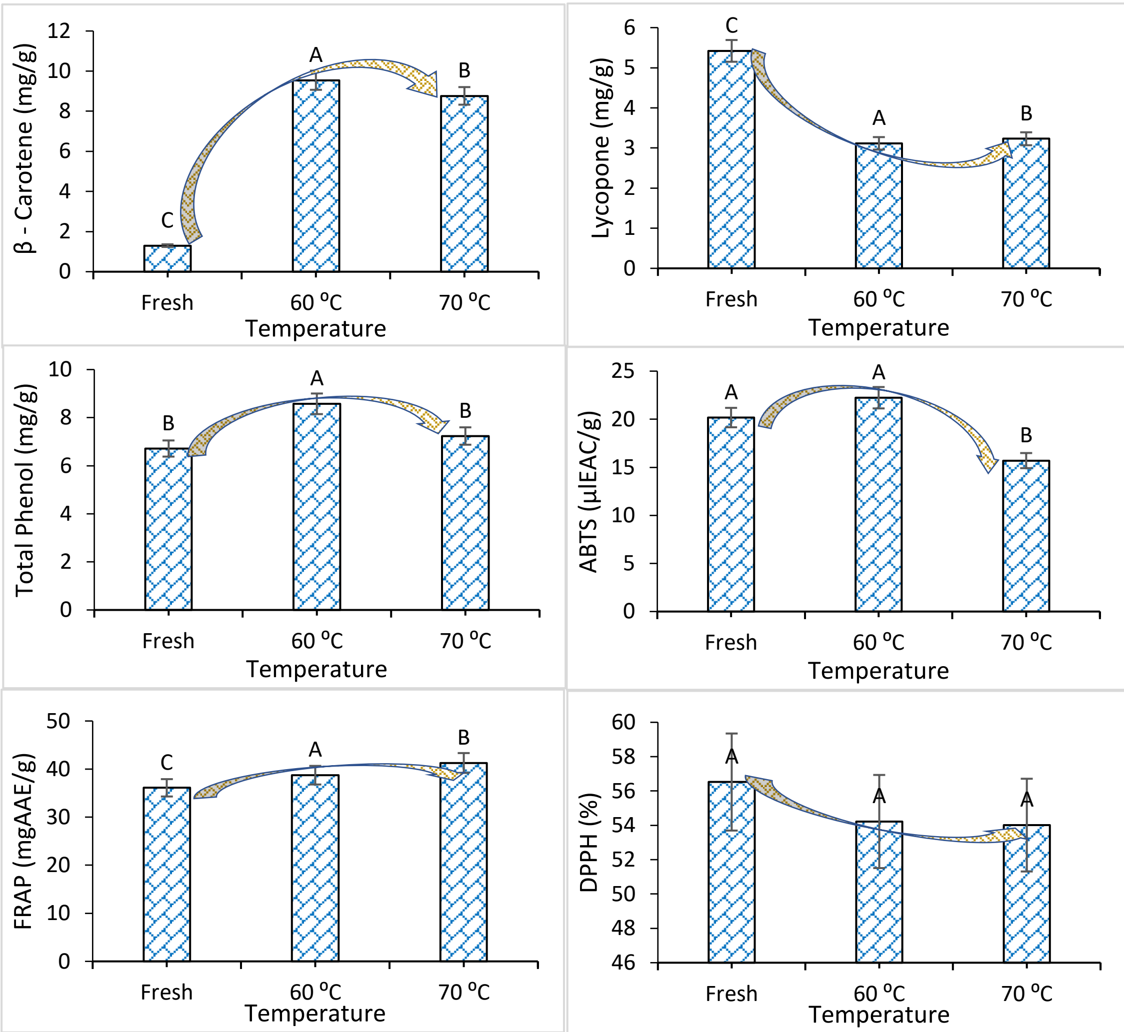

Figure 7. Antioxidant properties of fresh and dried watermelon: the column shows the magnitude of the content; the error bar denotes the standard deviation; the arrow shows the increment or decrement and any column with different alphabet are significantly different from one another at (P<0.05).

CONCLUSION

The findings of a research on foam-mat drying of watermelon pulp and quality estimation of evaluation of its flakes indicate the following:

i. The phytochemical properties of foam dried watermelon flakes which includes tannin, flavonoid, steroid, saponin, and terpenoid contents were found to be

0.34±0.021, 1.18±0.021, 0.82±0.001, 1.07±0.021, 0.10±0.004 mg g^{-1} respectively with alkaloid content of 0.45±0.014% for the drying temperature of 60ºC and 0.32±0.014, 1.09±0.007, 0.88±0.001, 1.03±0.021, 0.11±0.002 mg g^{-1} respectively, with alkaloid content of 0.39±0.007%, at drying temperature of 70ºC.

ii. The proximate composition of foam dried watermelon flakes was 3.98±0.021, 5.65±0.011, 4.06±0.063, 1.06±0.001, 3.51±0.014, 81.74±0.057% at constant drying temperature 60ºC and 4.44±0.014, 11.85±0.0008, 4.12±0.007, 1.12±0.000, 3.28±0.035, 75.2±0.019% at constant drying temperature 70ºC for the ash, fat, fibre, protein, and carbohydrates content, respectively.

iii. The antioxidant composition of foam dried watermelon which include β - carotene, lycopene content total phenol, ABTS, FRAP, and DPPH were 9.55±0.007, 0.312±0.007, 8.57±0.47, 22.44±2.31, 38.73±0.90 and 54.22±1.12 mg g^{-1} respectively for drying temperature of 60°C and 8.77±0.007, 3.23±0.014, 8.76±0.47, 15.7±2.31, 41.25±0.90 and 54.01±1.12 mg g^{-1} respectively for drying temperature of 70°C.

iv. The foam dried watermelon flakes at temperature of 60°C contains 17.34±0.184, 71.07±100.31, 0.15±0.007, 1.66±0.002, 0.50±0.002, 0.77±0.001, 46.26±0.028 mg 100 g^{-1} and 13.24±0.028, 0.13±0.001, 0.96±0.004, 1.12±0.001, 0.53±0.003, 0.81±0.006, 47.35±0.021 mg 100 g^{-1} at drying temperature of 70°C for vitamin A, B1, B2, B3, B6, B12, and C respectively, and this shows that the qualities of the foam dried flakes were preserved and safe for consumption.

DECLARATION OF COMPETING INTEREST

The authors declare that he has no conflict of interests.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Authors declare the contributions to the manuscript such as the following sections:

John Isa: Conceptualization, visualization, ınvestigation and review of relevant literatures, methodology, data curation, validation, formal analysis, writing-original draft, review, and editing.

Ayoola Olalusi: Conceptualization, ınvestigation, methodology, review, and editing.

Olufunmilayo Omoba: Visualization, ınvestigation methodology, formal analysis, validation, review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1102436

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 265-276

Research Article

Impact of Cassava Processing Mill Effluent on Physical and Chemical Properties of Soil in Akure, Ondo State, Nigeria

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ABSTRACT

The research aims reviewed impact of the Cassava Processing Mill Effluent (CME) on the physco-chemical properties of soils. Collected samples of three chosen areas at the Igbatoro community, Akure, Ondo State, Nigeria and labeled as A B C. Soil samples free from cassava mill effluent were likewise gathered from two unique areas marked D and E to serve as control samples at an interval of 15 cm depth from the top. Chemical changes occurred in the soil because of the release of effluent from cassava handling plants; the soil samples collected were analyzed in the laboratory utilizing the Atomic Absorption Spectrometry (AAS) method. The accompanying physical and chemical parameters were investigated; soil texture, soil porosity, particle size, TOC, pH, electrical conductivity, Pb, Zn, Cr, Fe, K, Ca, and Na. Results were compared with the result obtained from the control site Federal Environmental Protection Agency (FEPA) and World Health Organization (WHO) standards. Analysis shows that the soil samples with CME exceeds the WHO and FEPA standards. The result shows that the CME has contaminated the soil and made it unsatisfactory for agricultural purposes; this also affected the environment and the soil organic matter. Based on WHO and FEPA standard regulations, these metals exhibit hazardous concentrations. There was no huge expansion in Pb and Cr grouping of CME samples with the control tests. The chemical concentration of CME and its consequences for the soil propose its true capacity as a bio fertilizer particularly for K and Na contents. Findings shows that the effluent has great effect on the surrounding soil, and which leads to soil pollution, remediation should be practice.

RESEARCH ARTICLE

Received: 12.04.2022
Accepted: 10.11.2022

Keywords:

- Physico-chemical,
- CME, WHO and FEPA standard,
- Igbatoro environs,
- Heavy metals

To cite: Famuyini J and Sedara A (2022). Impact of Cassava Processing Mill Effluent on Physical and Chemical Properties of Soil in Akure, Ondo State, Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 265-276.* https://doi.org/10.46592/turkager.1102436

INTRODUCTION

Nigeria is the biggest cassava delivering country on the world and is no less than multiple times more than that of Brazil and has now multiplied the creation of Indonesia and Thailand (Odubanjo *et al.*, 2011; Obayelu *et al.*, 2022). Nigeria cassava creation has been growing beginning around 1960 when the country gain independence from Great Britain. The following cassava production figures were recorded for Nigeria, which shows an upward trajectory between TE1970 – TE2018 as 9.3 million tonnes (1970) to 59.5 million tonnes (2018) as indicated by *Ikuemonisan et al.* (2020). Consequently, in Nigeria and in most tropical nations, cassava has been the staple food and with the continuous improvement in the works, it is progressively changing from a starvation hold item and normal staple food to cash crop for metropolitan use and to an item thing for business sector. Today, cassava is the basic wellspring of dietary food energy for the vast majority living in the bog jungles, and a huge piece of the sub-moist jungles of West and Central Africa (Tsegia and Kormawa, 2002).

In this piece of the country, cassava tuber is taken care of and prepared for use mostly either as garri, starch, or as dried or wet cassava flour. All significant handling stage is in handling, and these prompts areas of cassava processing machines generally around the environment. Results got during this cycle is called cassava mill effluent (CME) include the solid and liquid waste. The significant limitation in cassava tuber as human food is the presence of toxic cyanogenic glycoside compounds in the tissues. Cassava tissues in like manner contain the catalyst linamarase, which can hydrolyse cyanogenic glycoside anyway the compound isn't arranged in comparative cell compartments as the cyanogenic glycosides (Ogbonna *et al.*, 2021). Cyanogenic glycosides are arranged inside vacuoles and the protein linamarase in the cell divider. Cyanogenic glycoside is filtered from vacuole and meet linamarase, a glucosidase, to convey $(CH_3)_2CO$ cyanohydrin from linamarin and 2-butanone cyanohydrin from lotaustralin (Conn, 1994). These cyanohydrins are unsteady and break down sharply to the relating ketones and hydrogen cyanide (HCN) at pH values more than 5 and temperatures above 300°C.

Cassava mill effluent creation has expanded emphatically because of expansion in cassava production. This mill effluent should be appropriately control prior to releasing forestall nitrogen-fixing deficiency microorganisms (Agbo *et al.*, 2021). Technical analysis revealed that discharged cassava processing effluent if not control may cause serious harm to the ecosystem (Antia *et al.*, 2021). This biowaste is considered a major contributor essentially to natural contamination and consumption of water asset quality because of the high chemical oxygen demand (COD) of liquid waste, high biochemical oxygen demand (BOD) of suspended solids (Plevin and Donnelly, 2004), high cyanide content and unpleasant odor of CME (Adeyemo, 2005). Contamination of those heavy metal played intense general wellbeing worry because of its ingenuity, harmfulness and non-biodegradability in the environment (Smah *et al.*, 2021).

It is very important to reduce its environmental impact because if it is not properly managed it will constitute nuisance to both terrestrial and aquatic life and cause a lot of havoc to vegetation's, houses, and bring about infection to microbe and infestation which can lead to environmental hazard. The aim is to evaluate impact of heavy metals levels and chemical attributes from effluent discharge in cassava mill on surrounding soil, in other to proffering solution to its improper disposal, and analyzed environmental hazards associated with cassava mill effluent.

MATERIALS and METHODS

Study area

Igbatoro people group, arranged in Akure North nearby government area of Ondo State, Nigeria, lies generally on latitude 70 09' 48.80'' and longitude 50 45' 4.70'' with height of 324.6 m (Ajayi *et al*., 2010). Its main relief feature is lowland type of landscape grouped under the coastal lowland of Western Nigeria within the tropical rainforest region. Average annual rainfall of the environment was recorded as; for 2005 is 1007.25 mm, 2006 is 1142.51 mm and 1232.60 mm (Ministry of Agriculture and Natural Resources, 2018). According to the meteorological agency record, the geology and area factors of the site are predominance rainy environment, warm, damp and moist with at least 0.25 mm or more, the maximum monthly mean Relative Humidity is 89% and minimum of 67% and annual monthly mean Temperature is between 30.7°C and 21.05°C. The soil texture of the sample site is sandy clay loam which make it significantly useful for farming occupation. Figure 1; show the location of Akure in the map of Nigeria.

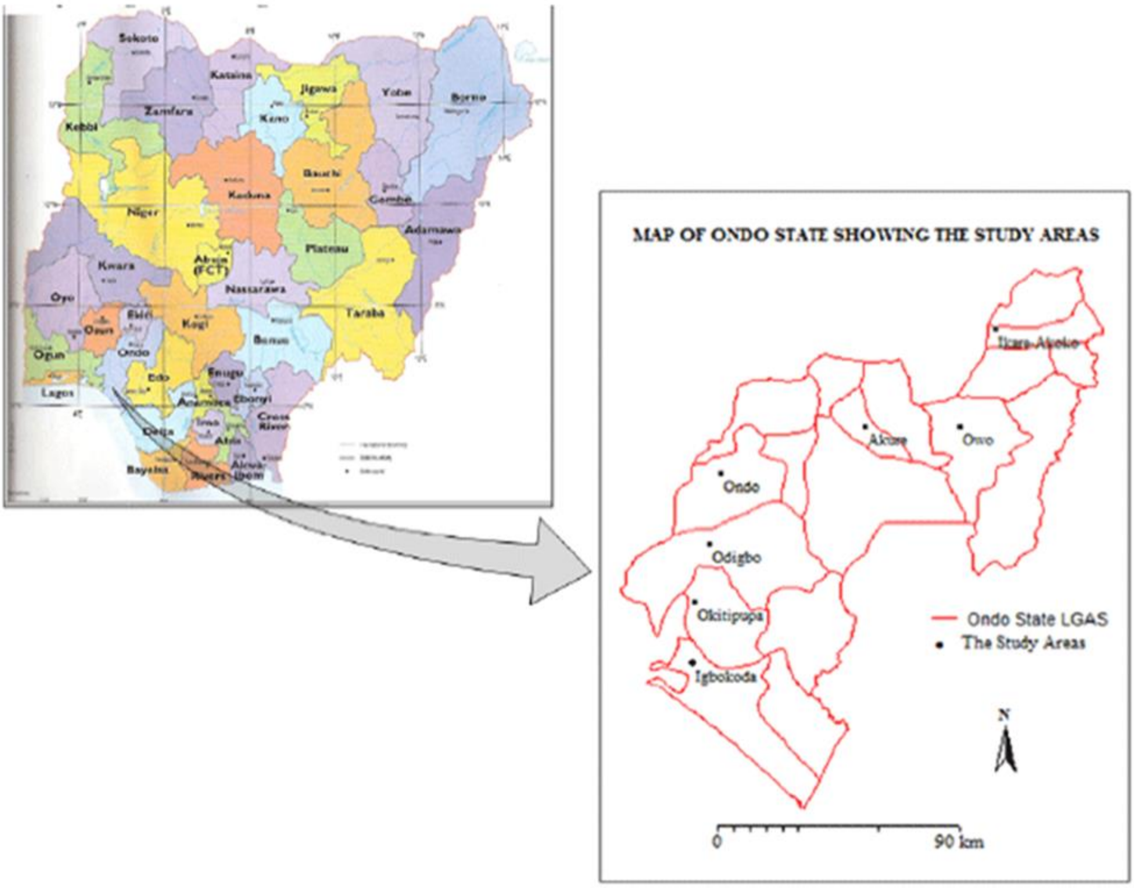

Figure 1. Study area shown in Nigeria map (Source: Ajayi *et al*., 2010).

Sampling

Three chosen areas in Igbatoro road, named as A B C for soil samples liberated from cassava mill effluent were likewise collected from two distinct areas marked D and E (controls).

Soil auger fabricated from department of agricultural engineering Federal University of Technology Akure was used for collection of soils at different depth, with everyone examined at the lab. Range of soil depth collected are from 15 cm, 30 cm, and 45 cm. Each sample obtained were mixed thoroughly and kept in a black polythene bag labeled accordingly.

Sample preparation and analytical procedure

Both samples were taken to Chemistry laboratory for physical analysis at Federal University of Technology Akure, Ondo State, Nigeria. Air dried process was carried out on the samples for a period of a week to retained elements present in it. Homogenization was carried out after air drying through a 2 mm sieve. Atomic Absorption Spectroscopy (AAS) method was carried out for quantitative determination of chemical elements (Izah *et al.*, 2017). The digested samples were taken to Sustainable Agro-tech Nigeria limited near NNPC mega station, kilometer 4/5, Benin Ilesa Expressway, Akure, Ondo state for the heavy metal's determination. Those metals analyzed for are Na, Ca, K, Zn, Fe, Pb and Cr. The data obtained is subjected to statistical analysis. A one-way analysis of variance (ANOVA) was carried out to determine differences between the samples and to compare the contaminated samples of cassava mill effluent with the non-contaminated samples i.e., control samples to know the significant differences. Duncan's Multiple Range Tests (DMRT) has been utilized to isolate mean of the samples.

Determination of soil pH

The pH in water technique was utilized (Etta *et al.*, 2019). 5 g of each dried soil test was put inside a receptacle, 50 ml of refined water was added, and the blend mixed for 30 minutes with glass pole. The pH meter was normalized and adjusted with support arrangement of pH 4.10 and 9.20. The anodes of the pH meter were submerged into the halfway settled suspension and the readings were taken. The terminals were flush with refined water and cleaned dry with clean channel paper after each example perusing.

RESULTS AND DISCUSSION

The major texture of the soils obtained were sandy clay loam and effect caused by cassava effluent discharged on the soils is illustrated in physico-chemical properties of samples displayed on Table 1. The pH of soil samples receiving CME ranged from 7.91 to 9.24 and the one without CME ranged from 7.62 to 8.22, which is high compared to those of control sites and to maximum of 7 neutral of the guidelines recommended by Nigerian Federal Environmental Protection Agency (FEPA, 1991) and World Health Organization (WHO, 1983) as shows in Table 2 and these have serious implications on crops (Enerijiofi *et al.*, 2017). The alkalinity could be because of the presence of hydrogen cyanide in the CME (Etta *et al.*, 2019). Figure 2 shows that alkalinity increase with depth in each of the destinations of contaminated soil samples aside from site C and this is attributed to the CME processing going on at the soil surface at the time this research has been carried out. The highest soil pH recorded was 9.24 compared to other sites and depths, which shows the soil is more acidic observed at Site C at 0-15 cm depth. This is because of the sloppiness of the ground towards site D. Soil highest pH values recorded in this study are in similar reach with those revealed in a few related investigations Rashad and Shalaby (2007) ; Oviasogie and Ofomaja (2007). Soil pH decides the accessibility of supplements and the power of poisonous substances as well as the physical properties of the soil and availability of enhancements and the force of harmful substances as well as the actual properties of the soil (Izah *et al.*, 2017). The pH values of these concentrated location show an overall high propensity for high availability of the metals; hereafter, this expands the bet of heavy metals plant take up.

Total Organic Carbon (TOC) of 1.17% at Site B was the highest value recorded at 0-15 cm depth, which is the top agricultural soils, while low Total Organic Carbon was observed at Site A, depth 0-15 cm, this is due the stagnation of cassava waste water on the surface for a longer period compared to other sites. The phosphorus content of the soil is high and the highest value of 76.20 mg kg^{-1} was observed in Site B.

Table 1. Physicochemical properties of the soil samples.

Sample	Depth (cm)	Particles Size			Texture	TOC	pH	E/C	P	CEC
Contaminated soil		Clay	Silt	Sand		%		mg kg^{-1}	mg kg^{-1}	mol kg^{-1}
Site A	0-15	31	3	77	Sandy Clay Loam	0.02	8.45	0.62	46.75	1.23
	15-30	28	2	81	Sandy Clay Loam	1.09	8.90	0.55	43.82	0.95
	30-45	31	3	77	Sandy Clay Loam	0.86	8.63	0.51	45.72	0.91
Site B	0-15	17	2	80	Sandy Loam	1.17	7.91	0.29	71.10	0.49
	15-30	23	2	74	Sandy Clay Loam	0.12	8.01	0.25	76.20	0.94
	30-45	30	3	66	Sandy Clay Loam	0.08	8.66	0.42	69.80	0.72
Site C	0-15	18	1	76	Sandy Loam	0.66	9.24	1.31	55.50	1.63
	15-30	28	0	67	Sandy Clay Loam	0.09	8.80	0.87	55.70	1.00
	30-45	16	0	79	Sandy Loam	0.98	9.11	1.24	50.60	0.98
Control Soil										
Site D	0-15	17	1	76	Sandy Loam	0.70	7.62	0.05	68.30	0.84
	15-30	30	2	60	Sandy Clay Loam	0.47	7.82	0.00	70.20	0.85
	30-45	21	0	76	Sandy Clay Loam	0.78	8.22	0.00	69.20	0.83
Site E	0-15	20	1	78	Sandy Loam	0.78	7.84	0.10	68.20	0.74
	15-30	30	4	68	Sandy Clay Loam	0.37	7.84	0.11	70.10	0.75
	30-45	20	1	70	Sandy Loam	0.75	7.84	0.11	69.10	0.73

TOC %: Total Organic Carbon, E/C: Electrical Conductivity, CEC: Cation Exchange Contents, P: Phosphorus

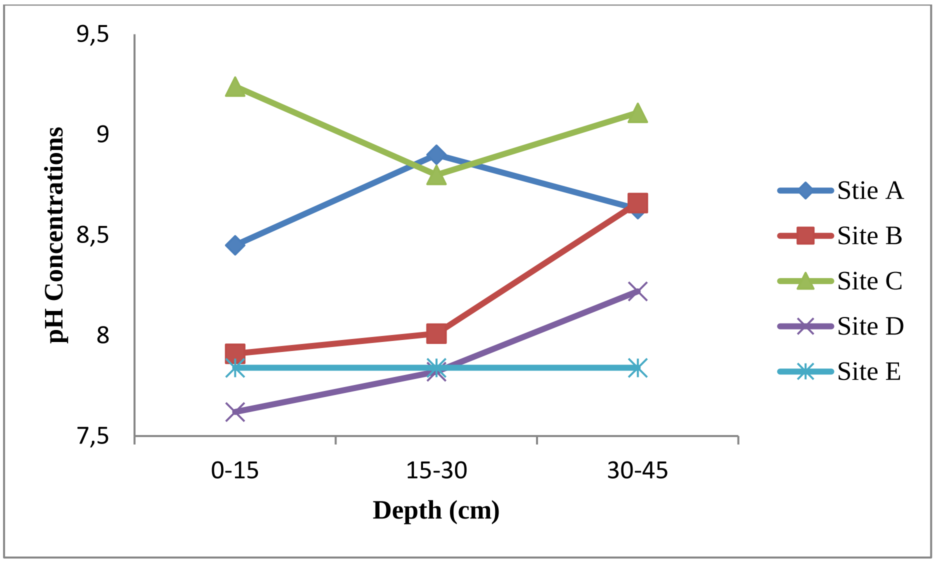

Figure 2. Soil pH Concentrations of CME soil samples at the sites locations.

The electrical conductivity of soil in the study areas ranges from 0.25-1.31 mg kg^{-1} for the soil samples receiving CME and the one without CME range from 0.00-0.1 mg kg^{-1}. Electrical conductivity is utilized for assessing soil saltiness (Izah *et al*., 2017). The Electrical Conductivity (E/C) and Cation Exchange Contents (CEC) are high in Site C with values of 1.31 mg kg^{-1} and 1.63 mol kg^{-1} respectively. This is because there is relationship between electrical conductivity of the soil and cation exchange. The qualities recorded in this study are because of expansion in concentration of soluble salts in correlation with the value recorded for control. The consequences of high electrical conductivity in soils are that there is sensible or huge presence of anions (Etta *et al*., 2019). The value in CME soil sample is still moderate in correlation with 4 mg kg^{-1} FEPA standards for soil quality.

Table 2. Concentration of heavy metals and non-heavy metals at various soil samples.

Sample	Depth (cm)	Heavy metals and non-heavy metals						
		Na	Ca	K	Cr	Zn	Fe	Pb
Contaminated soil		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Site A	0-15	4.40	28.29	65.12	0.46	1.91	267.75	1.00
	15-30	4.00	14.59	51.72	0.52	1.39	258.75	1.00
	30-45	4.70	32.99	62.92	0.66	2.13	318.75	1.00
Site B	0-15	4.60	38.69	68.42	0.18	2.06	195.75	0.60
	15-30	3.00	24.72	49.32	0.97	1.78	338.75	1.10
	30-45	2.20	22.00	50.62	0.92	1.71	268.75	1.10
Site C	0-15	5.30	39.89	69.22	0.38	2.74	242.75	0.80
	15-30	4.90	36.09	66.52	0.43	2.65	298.75	0.80
	30-45	2.90	17.69	49.42	0.08	1.51	118.75	0.20
Control Soil								
Site D	0-15	3.10	18.19	49.92	0.75	1.08	226.75	0.90
	15-30	1.60	12.99	43.82	0.67	0.28	206.75	0.70
	30-45	14.00	14.09	42.62	0.40	0.21	228.75	0.80
Site E	0-15	3.00	22.39	53.12	0.26	1.82	152.75	0.40
	15-30	4.50	27.39	66.82	0.49	2.63	163.75	0.80
	30-45	5.60	34.39	69.32	0.87	2.64	263.75	1.10

The total organic carbon ranged from 0.02 to 1.17%. This value is because of the release of the CME for certain items in organic matter and recommends presence of compostable substances in the effluent. Total organic carbon values of this study resemble qualities announced by Osakwe (2012), but similarly lower than the qualities revealed somewhere else in one more related study by Tukura *et al.* (2007). High values of phosphorus recorded in this study are not unexpected because cassava tuber is a good source of phosphorus in correlation with Osakwe (2012) study. For the texture of the samples, they increase in the following order, soil molecule size, propagation of sand fraction clay and followed by silt.

Soil cation exchange values range between 0.49-1.63 mol kg^{-1}. Cation exchange capacity is honestly connected with soil capacity of adsorbing heavy metals (Odubanjo *et al.*, 2011).

Results of the investigation of physico-chemical properties exposed those mean concentrations of some of the heavy metals including poisonous ones as Zn, Fe, and so on were totally observed to be very high comparative with those of the control sites, where (aside from Cr and Pb) a large portion of them were either not identified by any stretch of the imagination (Table 2).

Although, for non-heavy metals since the control site recorded lower mean concentration for vast all (aside from K) which has higher mean concentrations. The mean concentration of metal contents in all the soil samples that is, sites A-E, are very high concerning Fe (338.75 mg kg^{-1}), K (69.33 mg kg^{-1}), Ca (39.09 mg kg^{-1}), Na (14 mg kg^{-1}), Zn (2.74 mg kg^{-1}), Pb (1.10 mg kg^{-1}) and Cr (0.97 mg kg^{-1}) in a specific order. Among the heavy metals, Pb (0.60 ±1.00 mg kg^{-1}) and Cr (0.30 ± 0.55 mg kg^{-1}) recorded worrisome mean concentrations. While Fe (220.08 ± 281.75 mg kg^{-1}) and Zn (0.30 ± 0.55 mg kg^{-1}) recorded the highest mean concentrations (Table 4), since the least of these concentrations has outperformed the cutoff points passable in soil by regulatory, FEPA, 1991 (Nigerian Federal Environmental Protection Agency) and WHO, 1983 (World Health Organization) (Table 3), with the exception of chromium which is still between the limit point of FEPA and WHO standard. The high scope of iron from the soil analysis in the study region shows the accessibility of some oxidized agents subsequently, is viewed as vital for chlorophyll synthesis which doesn't meet the FEPA rule limit for plant development and crop production will be massively reduced because of the pollution of the soil by CME which is similar to Etta *et al.* (2019) study. Moreover, regulatory data were not ethically accessible for most of the metals for the different ecological media, especially soil, in this manner making data examinations for safe restricts troublesome errand.

Table 3: Concentrations of heavy metals and non-heavy metals for soil samples (WHO, 1983; FEPA, 1991).

Elements	Results
Cr	2.00
Pb	0.01
Fe	0.30-1.5
Zn	3.00
Na	-
Ca	-
K	-
PH	7.00

Table 4. Mean concentrations of metals and non-metals of contaminated and control soil sample.

Metals	Contaminated samples			Control sample	
	Site A	Site B	Site C	Site D	Site E
Na	4.37±0.09[c]	3.13±0.21[a]	2.73±2.37[b]	2.00±0.03[b]	4.30±0.07[c]
Ca	25.29±0.16[d]	28.15±0.30[c]	30.62±0.67[c]	14.66±0.45[b]	27.99±0.08[d]
K	59.92±0.63[e]	15.26±0.61[b]	60.71±0.94[d]	44.58±0.99[c]	61.96±1.47[e]
Cr	0.55±0.02[a]	0.65±0.06[a]	0.28±0.02[a]	0.56±0.05[a]	0.52±0.03[a]
Zn	1.81±0.02[b]	1.81±0.04[a]	2.13±0.15[ab]	0.49±0.03[a]	2.32±0.04[a]
Fe	281.75±1.19[f]	254.99±17.97[a]	220.05±0.94[e]	217.20±5.76[d]	192.15±1.43[b]
Pb	1.00±0.07[ab]	0.86±0.06[a]	0.57±0.06[a]	0.75±0.06[a]	0.73±0.04[a]

**Difference in superscript in a column means there is significant difference*

In this study DMRT analysis was used to measure which metal has the least concentration (superscript a-e) in the soils in the different sites. The Duncan multiple range test (DMRT) showed that the CME concentration had significant effect in on the Cr, Fe, Pb, K, Ca contents of the soil for all the sites (Tables 5). Impact of CME concentration on Site A showed that Cr (0.55±0.02[a]) and Pb (1.00±0.07[ab]) has the lowest concentration compared to other metal. In Site B the lowest metals are Na (3.13±0.21[a]), Cr (0.65±0.06[a]), Zn (1.81±0.04[a]), Fe (254.99±17.97[a]) and Pb (0.86±0.06[a]). Site C the lowest concentration ranged from Cr (0.28±0.02[a]), Pb (0.57±0.06[a]) and Zn (2.13±0.15[ab]). Site D has its lowest ranged of metals from Zn (0.49±0.03[a]), Cr (0.56±0.05[a]) and Pb (0.75±0.06[a]). While Site E has east metal concentration for Cr (0.52±0.03[a]), Zn (2.32±0.04[a]) and Pb (0.73±0.04[a]). It was observed that the least common metals with low concentration are Cr, Zn and Pb, this was also reported Odubanjo *et al.* (2011) study. The concentration of the relative multitude of metals investigated in the soil getting CME in site B and C diminished down the profile aside from K and Cr (Table 2). Higher increase in concentration of K and Fe as well as the presence of Na and Ca in cassava effluent demonstrates the way that it tends to be utilized as a bio-compost. The dissemination of heavy metals concentration in CME soil showed that it was by and large higher at the topsoil than the sub and base soils except for site A where might be a few synthetic tasks, for example, percolation, infiltrations draining e.t.c which had occurred on the soil surface before samples were collected. This higher level of metals on the topsoil is normal since the topsoil is the resource with CME. The level of heavy metal for all the locations was altogether higher than the levels seen in the control site asides from site E which may come about because of the interaction utilized for collecting the soil sample, or at least, when the soil is excessively hard for the soil auger to drill in, it was currently wet with water.

This infers that the contamination degree increment is dependent on the heavy metals due to the effluent from the cassava mill to the soil because of the nature of the soil texture. Fe is mostly concentrated in the site as shown in Table 4, which agrees with Aluko and Oluwande (2003) that soils concentration is Fe based. Contamination of Fe cannot indisputably be connected to waste cassava effluent but can be from other sources Eddy *et al.* (2003). Nonetheless, express degrees of Fe in soil points to uncontrolled site which is very near the mill while sites far from it are show low concentration of Fe, this could have been because of cassava mill effluent exposure of Fe in the soil examined and this result agrees with Odubanjo *et al.* (2011). Nonetheless, for a large portion of the soil tested, it was observed that degrees of Ca, K, and Fe, are likewise very high and could be owing to the way that these groups of metals constitute more of east crust metals (Mitchell, 1964). Also, it could be climate reaction on the soil (Aubert and Pinta, 1977), like heat and humidity in general thereby, changing potassium (K) degree from 20 to 5000 ppm. Soil metals exposed in this region have severe wellbeing inference on inhabitants living in that environment, inventory wellbeing impacts related to openness of the site to poisonous heavy metals.

Penetration of the metal in groundwater, can cause contamination and pollute the rivers in communities surrounding the mill, drinking the water can damage the liver, gastrointestinal tract (Adedara *et al.*, 2011). Body tissues and organs are damaged by encountering toxic heavy metals (WHO, 1996). Also, it can kill silently because if compiles itself in body before eventually leading to death (Nriagu, 1988). People living around in the study area are on the risk of a silent epidemic, because of findings in the research.

Table 5. Chemical composition cassava mill effluent effect on soil samples and control soil samples.

Elements	Sources of variation	DF	SS	MS	F ratio	*F-value*	
	CME SAMPLES						
Cr	Treatment	2	-0.688	-0.344	-2.765	*3.40*	**
	Error	24	2.930	0.124			
	Total	26	2.296				
	CONTROL SAMPLES						
	Treatment	1	-0.876	-0.876	-4.133	*4.96*	**
	Error	10	2.120	0.212			
	Total	11	1.244				
	CME SAMPLES						
Zn	Treatment	2	-10.508	-5.245	-3.503	*3.40*	**
	Error	24	35.938	1.497			
	Total	26	25.430				
	CONTROL SAMPLES						
	Treatment	1	-5.273	-5.273	-3.503	*4.96*	**
	Error	10	15.053	1.505			
	Total	11	9.780				
	CME SAMPLES						
Fe	Treatment	2	-175251.75	-87625.87	-5.219	*3.40*	**
	Error	24	402952.316	16789.680			
	Total	26	227700.568				
	CONTROL SAMPLES						
	Treatment	1	-114293.76	-114293.8	-4.538	*4.96*	**
	Error	10	251841.618	25184.162			
	Total	11	137547.86				
	CME SAMPLES						
Pb	Treatment	2	-1.892	-0.946	-3.311	*3.40*	**
	Error	24	6.856	0.286			
	Total	26	4.961				
	CONTROL SAMPLES						

	Treatment	1	-1.636	-1.636	-4.368	*4.96*	**
	Error	10	3.745	0.375			
	Total	11	2.109				
	CME SAMPLES						
Na	Treatment	2	-42.577	-21.288	-3.463	*3.40*	**
	Error	24	147.537	6.147			
	Total	26	104.960				
	CONTROL SAMPLES						
	Treatment	1	-26.853	-26.853	-3.789	*4.96*	**
	Error	10	70.873	7.087			
	Total	11	44.020				
	CME SAMPLES						
Ca	Treatment	2	-2137.933	-1068.967	-3.362	*3.40*	**
	Error	24	7630.713	317.946			
	Total	26	5492.79				
	CONTROL SAMPLES						
	Treatment	1	-1227.082	-1227.082	-4.14	*4.96*	**
	Error	10	2963.192	296.319			
	Total	11	1736.110				
	CME SAMPLES						
K	Treatment	2	-14013.291	-7006.645	-5.361	*3.40*	**
	Error	24	31369.131	1307.047			
	Total	26	17355.840				
	CONTROL SAMPLES						
	Treatment	1	-7828.035	-7828.035	-4.522	*4.96*	**
	Error	10	17312.905	1731.291			
	Total	11	9484.870				

Hints: MS- Mean of Square, DF- Degree of Freedom, MS- Mean of Square, SS- Sum of Square
Cr-Chromium, Zn-Zinc, Fe-Iron, Pb-Lead, Na-Sodium, Ca-Calcium, K-Potassium
*** means significant difference, *means non-significant difference*

CONCLUSION

This study showed that for physico-chemical properties of soil samples receiving the cassava mill effluent increases in pH along the soil profiles for all the samples, this leads to higher levels of available K, and conductivity capacity of the soils which revealed that CME had noticeable accessibility on chosen physico-chemical. The soil samples analytical results showed that CME has immensely polluted the soil and made it unfit for agricultural activities. It is on this note that it's concluded that CME had both negative and positive effects on the study area and its environs. Educating campaign should be given to the processor by the Agricultural extension workers on how to detoxify CME in accordance with FEPA and WHO standards. Appropriate methods of disposal of both solid and liquid effluent from cassava are recommended for save and healthy condition of Igbatoro road environment. Further study should be carried out on converting cassava effluents into more useful materials and potential usage as biofertilizers.

DECLARATION OF COMPETING INTEREST

The authors declare that there is no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

This research work was carried out in collaboration with the authors (Famuyini and Sedara).
John Famuyini contributes to the investigation, methodology, writing - original draft.
Adewale Sedara contributed in the section of review and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1190083

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 277-291

Research Article

Precipitation Intensity-Duration Occurrence Models Development for Designated Locations in the Southern Humid Rain Forest Zones of Nigeria

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ABSTRACT

This research work examined the tendencies and patterns in the rainfall in carefully chosen localities of Southwest and South-South Nigeria. Rainfall data from 1983-2014 in Ibadan, Lagos, Benin, Calabar, Port Harcourt and Warri were used for this study. Standard deviation, mean, coefficient of skewness, coefficient of kurtosis, coefficient of variation and standardized anomaly index were engaged to analyze the data and describe the distribution of rainfall in these stations. The data were analyzed using statistical package for social sciences, SPSS 17 and Minitab 16. The outcomes revealed that the maximum annual rainfall occurred at Warri station 4489.80 mm in the year 2008 and the minimum occurred at Benin 229.10 mm in 2005. Also, Benin has the maximum coefficient of variation of about 24.72%, while Port Harcourt has the minimum coefficient of variation of about 12.71%. Warri station was positively skewed indicating that it experienced frequent low rainfall values, while Port Harcourt was approximately symmetrical skewed. Warri has kurtosis coefficient of 4.45 which is highest among others. However, the patterns of rainfall in these areas are random or fluctuating. It is recommended that models built on the perceived decreasing rainfall, such as drainages, dams, have to be reviewed.

RESEARCH ARTICLE

Received: 16.10.2022
Accepted: 12.11.2022

Keywords:

- Analysis,
- Climate,
- Rainfall,
- Linear trends model,
- Variability

To cite: Emeka-Chris CC, Obineche CI and Unanka BO (2022). Precipitation Intensity-Duration Occurrence Models Development for Designated Locations in the Southern Humid Rain Forest Zones of Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 277-291.* https://doi.org/10.46592/turkager.1190083

INTRODUCTION

In Nigeria, the development of IDF models is still in its growing path and it is inadequate to the extent of available data (Nwaogazie *et al.*, 2019). Oyebande (1982) derived IDF model for the western region without adequate data and applied Gumbel EVT -1distribution to the maximum period of ten years records to derive rainfall IDF models. In Humid Forest Zones of Nigeria, recent studies on rainfall IDF development have been done in Southern Nigeria. Akpan and Okoro (2013), Nwaogazie and Duru (2002) developed Rainfall Intensity Frequency Models based on statistical method of least squares. Also, Okonkwo and Mbajiorgu (2010), Ologhadien and Nwaogazie (2014) developed IDF curves of extreme rainfall for South Eastern Nigeria based on generalized accumulated rainfall. Akpen *et al.* (2016) studied rainfall events for Makurdi metropolis. The IDF curves developed were in accord with IDF theory of shorter recurrence periods of 2 to 10 years. Life-threatening precipitation actions cause contamination of the water quality, ruin of properties and harm of livelihood owing to deluging. Extreme environmental events, caused by climate change have become a major factor in the variability of rainfall trends in Nigeria and the world at large. Such actions include floods, drought, rainstorms, and high winds, have severe consequences for human society.

Among all forms of precipitation, rainfall is the one which affects agriculture most (Onwualu *et al.*, 2006). As such, it is necessary to note the methods for measuring and analysing rainfall data. The amount of rainfall is expressed as depth in cm (or mm), which falls on a level surface. The principal characteristics of a storm are its intensity, duration, total amount and its frequency or recurrence interval.

The IDF relationship is a mathematical relationship among rainfall intensity *i*, duration, *d*, and the return period, *T* (equivalent to the annual frequency of exceeding referred to as “frequency”). Mathematical curve fitting is nevertheless, easily adapted to the computer, and the results can be neatly and completely described by a few parameters. Identification of homogenous regions may also be adopted in analyzing rainfall data. A standardized area is defined as a group of sites that can be described by the same statistical distribution (Raiford *et al.*, 2007). The focus of this study is to determine the precipitation intensity - duration occurrence models development for designated locations in the southern Humid Rain Forest zones of Nigeria using Gumbel distribution and to relate outcome to the standardized anomaly index.

MATERIALS and METHODS

The study areas are in Humid Rain Forest Zones of Nigeria. Nigeria lies between Latitudes 4-14° North and Longitudes 2° 2' and 14° 30' East. It estimated land mass of 923.769 km^2, a North – South length of approximately 1450 km and a West-°East breadth of almost 800 km. The total land boundary is 4047 km, whereas the coastline is 853 km. The study locations include Ibadan and Lagos (West) while; in the South we have Calabar, Edo, Port-Harcourt and Warri (NFRA, 2008) are shown in Table 1.

Table 1. Characteristics of the meteorological stations of the study cities.

Location	State	Coordinate	Agro-ecological zones	Data Range
Ibadan	Oyo	07° 23'N, 03° 55'E	Western Moist Forest	1983- 2014
Lagos	Ikeja	06° 27'N, 03° 23'E	Western Moist Forest	1983- 2014
Benin	Edo	06° 10'N, 05° 37' 20"E	Central Moist Zone	1983 - 2014
Calabar	Cross River	04° 57'N, 08° 19'E	Eastern Moist Forest	1983 - 2014
Port-Harcourt	Rivers	4.75° N, 07°E	Eastern Moist Forest	1983- 2014
Warri	Delta	05° 31'N, 05° 45'E	Central Moist Zone	1983- 2014

National Food Reserve Agency (NFRA, 2008)

Climate

The climate of Nigeria is tropical with variable rainy and dry season. In southeast it is hot and wet most of the year, while in the southwest it is dry. Length of rainy season decreases from south to north. In the humid rain forest zone, the rainy season lasts from March to November. The southwest has large area of forest which has been replaced by cocoa and rubber plantation.

Data requirement and collection for the study

The rainfall depths data are vital in this research for smaller durations viz., 5, 10, 15, 20, 30, 60, 120, 180, 240, 300 and 360 minutes. Data were collected from National Root Crop Research Institute (NRCRI), Umudike and the Nigeria Meteorological Agency, (NIMET), Lagos. The length of the records used for all the stations are same 32 years (from 1983 to 2014).

Data Analysis

Analyzing trends of rainfall

In analyzing the required data and testing the normality of the time series data, the descriptive statistical techniques/tools were used. They include Mean yearly (Annual) rainfall for each study area, Yearly rainfall standard deviation for each study area, Standard coefficient of skewness Coefficient of variation, Standardized anomaly index (SAI) and Graphical plots.

Mean yearly (annual) rainfall

This is a measure of central tendency. Mathematically, it is denoted as $\bar{X}$ and computed as:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

Where:

$\bar{X}$= mean yearly rainfall

x_i= yearly rainfall values (mm)

n= total number of observations.

Yearly rainfall standard deviation

This is a measure of dispersion. The standard deviation measures the absolute dispersion for variability. The greater the standard deviation, the greater will be the magnitude of the deviation of the yearly rainfall values from the mean yearly rainfall for the periods.

A small standard deviation means a high degree of uniformity of the yearly rainfall values.

Computationally, it is denoted as σ and given by

$$\sigma=\sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{X})^2}{n-1}} \tag{2}$$

Where:

x_i= annual rainfall for the year

$\bar{X}$= mean annual rainfall

n= total number of observations

σ= standard deviation

Standard coefficient of Skewness

To measure the co-efficient of skewness, one can make use of the Karl Pearson's co-efficient of skewness which is based upon the difference between mean and mode. The difference value is divided by the standard deviation to give the relative measure. This is obtained using the formulae:

$$\text{Coefficient of Skewness} = \frac{Mean-Mode}{Standard\ deviation} \tag{3}$$

When, Skew > 0: Right skewed distribution that is most values are concentrated on left of the mean with extreme values to the right.

Skew < 0: Left skewed distribution that is most values are concentrated on the right of the mean, with extreme values to the left.

Skew = 0: Mean = Mode = Median; and distribution is symmetrical.

Standard coefficient of Kurtosis

It refers to the degree of flatness or peakness. When a distribution is normal or symmetrical, the co-efficient of kurtosis is equal to 3. When it is more than 3, it is more peaked than the normal and when it is less than 3, it is less peaked than the normal. Mathematically,

$$\text{Kurt (x)} = \frac{\mu^4}{\sigma^4} \tag{4}$$

Where:

μ^4= fourth moment of the mean

σ^4 = standard deviation

Gumbel Theory of Distribution

The Gumbel theory of distribution is the most widely used distribution for IDF analysis owing to its suitability for modeling maxima (Elsebaie, 2012). Frequency precipitation

P_T (in mm) for each of the duration with a specified return period T (in year) is given by the following equation.

$$P_T = P_{ave} + K\,S \tag{5}$$

Where K is Gumbel frequency factor given by:

$$K = \frac{\sqrt{6}}{\pi}\left[0.5772 + In\left[In\left[\frac{T}{T-1}(8)\right]\right]\right] \tag{6}$$

Where P_{ave} is the average of the maximum precipitation corresponding to a specific duration.

Log Pearson Type III

The LPT III distribution involves logarithms of the measured values. The mean and the standard deviation were determined using the logarithmically transformed data.

$$P*_T = P*_{ave} + K_T\ S \tag{7}$$

K_T is the Pearson frequency factor which depends on return period (T) and skewness coefficient, Where $P*_T$, $P*_{ave}$ are as defined previously.

Coefficient of variation

This is a measure of relative variation. It is used when comparing the variability of two or more than two series. That series for which the coefficient of variation is greater is said to be less consistent or less uniform or less stable. On the other hand, a series which has less coefficient of variation is more consistent and more stable.
Mathematically,

$$\text{Coefficient of variation, CV} = \frac{\sigma}{\bar{X}}\ x\ 100 \tag{8}$$

Where:
σ= yearly rainfall standard deviation
$\bar{X}$= mean annual rainfall

It is clear from above that dispersion (variation) measures the extent to which the observations vary from some central value like the mean. They served as a basis for the control of the variability in the yearly data.

It is clear from above that dispersion (variation) measures the extent to which the observations vary from some central value like the mean. They served as a basis for the control of the variability in the yearly data.

Standardized Anomaly index (SAI)

It is used in the analysis of rainfall variability. It is given as

$$\text{SAI (Z-scores)} = \frac{x_i - \bar{X}}{\sigma},\ i = 1, 2 \ldots 0. \tag{9}$$

Where:
x_i= yearly observations
$\bar{X}$= mean annual rainfall
σ = yearly rainfall standard deviation.

Statistical and graphical analysis
Graphical plots were used to plot annual rainfall values and to reveal trends (variations) and patterns in rainfall over the thirty-two years period for each study area. Statistical package for social sciences (SPSS) 17 and Minitab 16 was used in the analysis. Gumbel distribution methodology was used to perform the flood probability analysis. The excel solver methods used was the Generalized Reduced Gradient (GRG Solver) which is for optimization of nonlinear equations and the Linear Programming Solver (LP Solver) for linear equations.

RESULTS AND DISCUSSION

The result of the annual rainfall series from 1983 to 2014 is presented in the Table 2.

Table 2. Annual series of rainfall (mm) from 1983-2014.

YEAR	LAGOS	IBADAN	BENIN	CALABAR	Port Harcourt	WARRI
1983	1470.7	865.4	1657.9	2308.8	1632	2522.6
1984	1432	1382.2	1225.6	2508.4	2095.6	2741.4
1985	1986.6	1460.9	1557.7	2963.2	2395.7	2958.8
1986	1533.6	1297.7	1313.2	2611	2283.1	2887.1
1987	2048.27	1285.8	2419.2	2915.5	2261.3	2147.3
1988	2432.1	1408	2007.3	2814.7	2420.9	2442.6
1989	1821.7	1344.4	1939.8	2767.3	2160.2	2636.4
1990	2031.2	1279.9	2588.4	2729.1	2073.3	2567.7
1991	1867.8	1369.3	2439.2	2662.9	2094.4	2952.9
1992	1357.6	1072.7	2026.9	2896.3	1913.5	2944.5
1993	1837.1	1257.3	1899.1	2511.4	2359.8	2976.9
1994	1355	1002.7	2595.3	2904.6	2375.2	2870.7
1995	1977.4	1534.9	2677.9	3581.7	2523	3449.4
1996	1982.6	1647.9	2507	1084	2349.5	2592.1
1997	1699.8	1195.3	2082.8	3492.2	2329.8	2906.2
1998	953.5	920.6	2204.4	2802.7	2563.1	2537.3
1999	2068	1605.4	2164	3004.1	2498.2	3127.6
2000	1458.9	1240.1	2257.7	2750.2	1993.7	2879.9
2001	1310	1279.7	2424.3	3309.5	2123.4	2400.2
2002	1523.2	1447.8	2422.2	2797.7	2186.2	3307.4
2003	1575	1569.5	1860.1	2561.7	2349.6	2359.9
2004	2155.6	1327.4	2239.8	2356.1	1875	3138.5
2005	1746	1226.2	229.1	3008	1973.5	1925.8
2006	1364.6	1261.2	2183.9	2607.4	2975.9	2547.3
2007	1073.6	985.8	1904.6	1225	2362.2	2642.4
2008	939.2	1743.8	2727.7	3029.5	1977.4	4489.8
2009	1707.6	1702.2	2417.3	2586.1	2120.7	2656.1
2010	2086.8	1539.5	2663	3770	1998.4	2896.7
2011	2172.1	1639.8	3068.7	3754.6	2453.1	3179.5
2012	2214.3	1598.3	2568.9	3028.4	2120.7	3089.5
2013	2569.5	1965.4	2530.4	2810.2	1860.4	2307.6
2014	2450.5	2049.5	2395.3	2685.5	1636.8	2108.5

Table 3. Descriptive statistics of annual rainfall of study areas.

Yearly Rainfall (mm)	No. of Years	Minimum	Maximum	Mean	Standard Deviation	Skewness Coefficient	Kurtosis	CV
Lagos	32	939.2	2569.5	1756.31	416.61	-0.10	-0.58	23.72
Ibadan	32	865.4	2049.5	1390.83	276.66	0.30	0.20	19.89
Benin	32	229.1	3068.7	2162.46	534.52	-1.61	4.13	24.72
Calabar	32	1084	3770.0	2776.18	558.85	-1.14	3.41	20.13
Port Harcourt	32	1632	2975.9	2197.99	279.29	0.91	0.23	12.71
Warri	32	1925.8	4489.8	2787.21	464.16	1.31	4.45	16.65

CV = Coefficient of variation.

From Table 3, the results show that Warri recorded the highest mean minimum and maximum values of annual rainfall; Ibadan has the lowest mean and maximum annual rainfall while Benin recorded the least minimum annual rainfall. Lagos has annual rainfall values fairly symmetrical with skewness coefficient of -0.10. The annual rainfall values here are light tailed distribution with kurtosis of -0.58 and are said to experience platykurtic distribution. The coefficient of variation for the annual rainfall for Lagos is obtained as 23.72%, indicating variability in annual rainfall distribution. Ibadan has an annual rainfall distribution fairly symmetrical, with skewness coefficient of 0.3; the kurtosis value of 0.20, which is greater than zero and so the rainfall values have leptokurtic distribution with heavier tails and a coefficient of variation of 19.89%. Benin has a rainfall distribution highly skewed with a skewness coefficient of -1.16, while the kurtosis value is 4.13, its distribution has heavier tails and it is a leptokurtic distribution and a coefficient of variation of 24.72%, which indicates more variability. Calabar is negatively skewed with skewness coefficient of -1.14 indicating that the rainfall values are highly skewed and frequently high. The kurtosis coefficient and coefficient of variation for Calabar are high with values as 3.41 and 20.13%; Calabar experiences leptokurtic distribution with kurtosis of 3.41, which is greater than zero. Port Harcourt is moderately skewed with skewness coefficient of 0.91, signifying that rainfall values are neither low nor high. The kurtosis coefficient for Port Harcourt is 0.23, showing that it has a normal distribution, which is also known as mesokurtic distribution. There is less variability in annual rainfall values with coefficient of variation of 12%, which is the lowest among the six stations examined. Warri has positively skewed rainfall distribution, with skewness coefficient of 1.31. Its kurtosis value is 4.45. This shows that Warri experiences leptokurtic distribution.

Results of the Standardized Anomaly Index for the six states

The result of the standardized anomaly index for Lagos is shown in Figure 1.

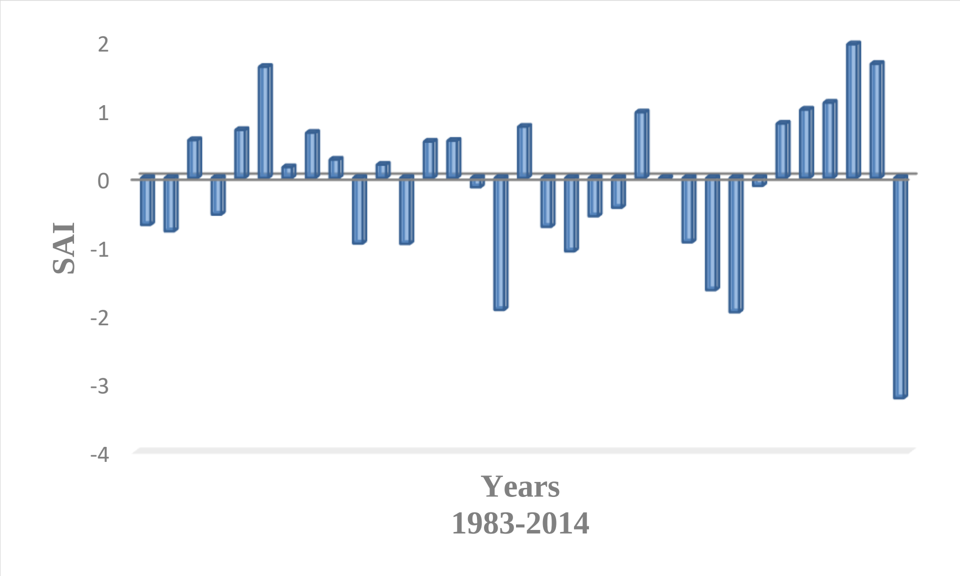

Figure 1. Standardized anomaly index for annual total rainfall at Lagos.

Lagos experienced a positive annual rainfall anomaly index above average from 1983 to 1997, with 6 respite years of negative anomaly index below long-term average. However, from 1998 there was a negative annual anomaly index below average with 2 respite years of positive anomaly index above long-term average until 2009. After 2009, there was positive departure, with long positive anomaly index above average up to 2014. In 1988, highest positive annual rainfall anomaly index above average was recorded, while the lowest negative rainfall anomaly index below average was recorded in 2008.

The result of the standardized anomaly index for Ibadan

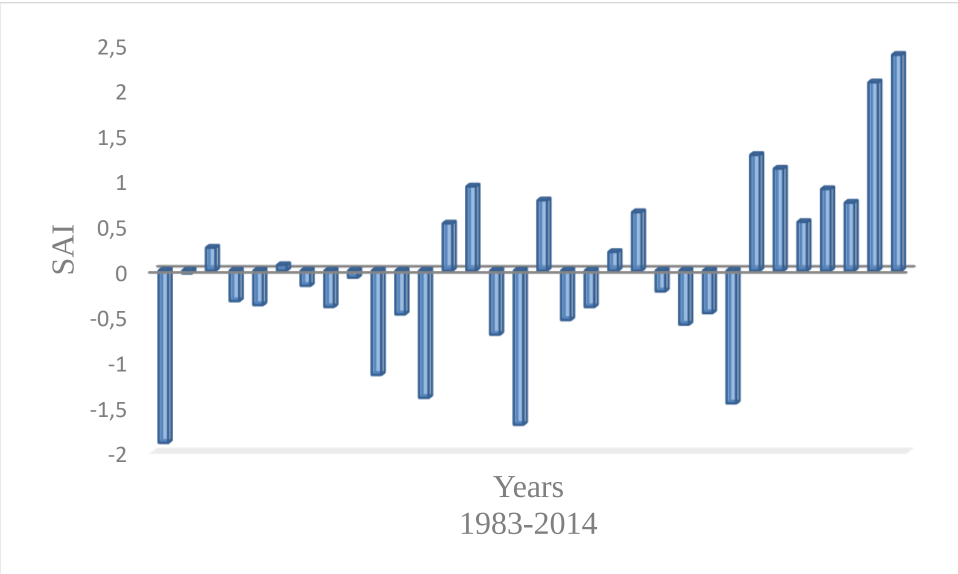

Figure 2. Standardized anomaly index for annual total rainfall at Ibadan.

Below long-term averages annual rainfall persisted during the period spanning 1983 to 2007, with 8 respites of positive anomaly index average years. Then there was strong positive departure above averages from 2008 until 2014 indicating period of high rainfall. Ibadan experienced highest rainfall anomaly index above average in 2014 and lowest negative rainfall anomaly index below average in 1983.

The result of the standardized anomaly index for Benin

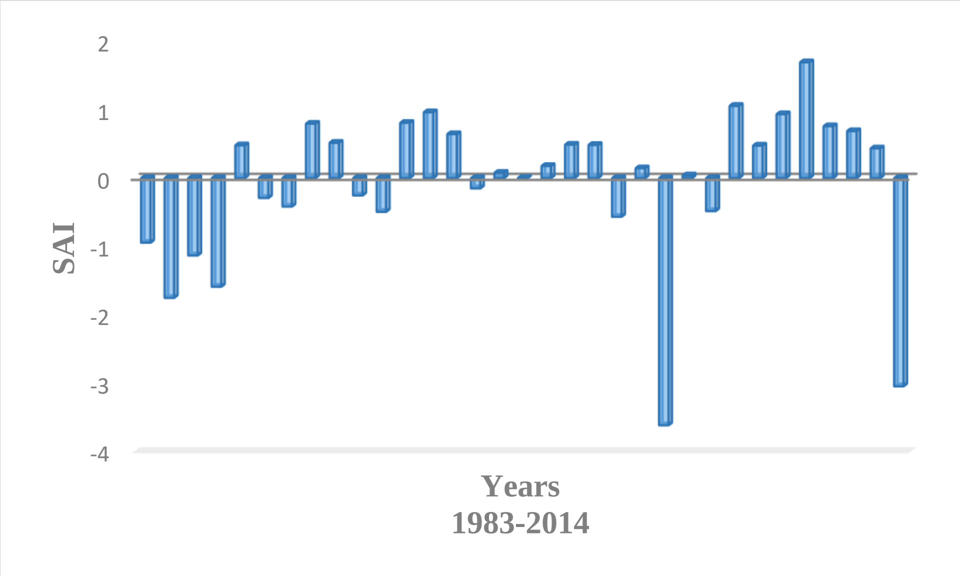

Figure 3. Standardized anomaly index for annual total rainfall at Benin.

Benin was marked with below long-term average between 1983 and 1986 indicating period of low annual rainfall. After 1986, there was above long-term averages of annual rainfall during the period spanning 1987 to 2014, with 9 respites of negative anomaly index below average.

The result of the standardized anomaly index for Calabar

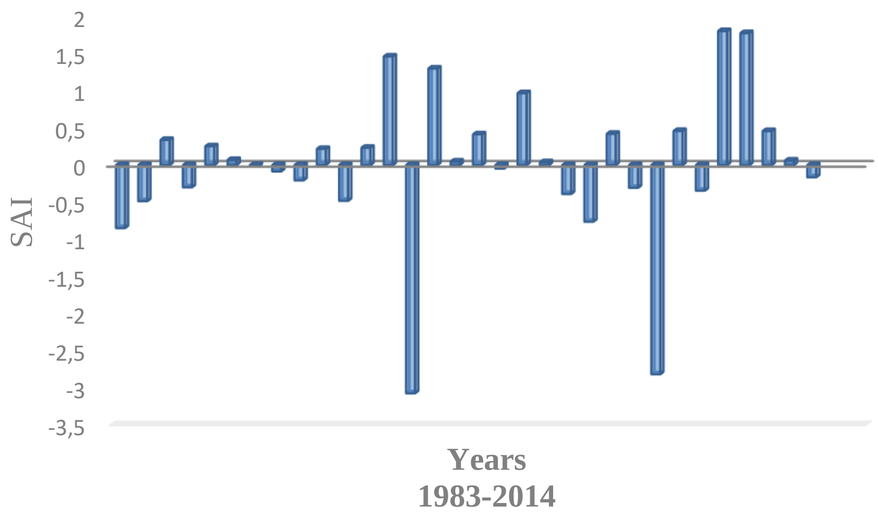

Figure 4. Standardized anomaly index for annual total rainfall at Calabar.

Below long-term averages of annual rainfall persisted during the period spanning 1983 -1995 with 5 respites of positive anomaly index above average indicating period of low rainfall years at Calabar. After 1995, there was alternate positive anomaly index above average and negative rainfall anomaly index below average until 2014.

The result of the standardized anomaly index for Port Harcourt

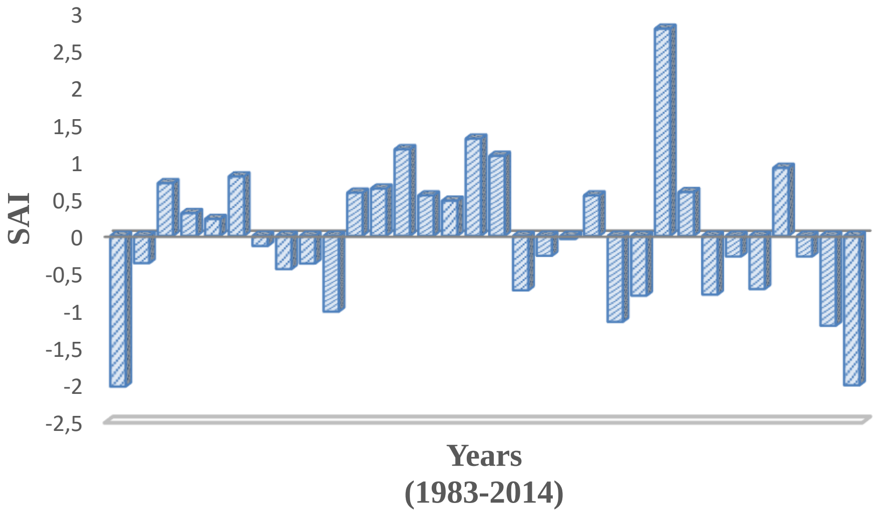

Figure 5. Standardized anomaly index for annual total rainfall at Port-Harcourt.

Port Harcourt was marked with below average annual rainfall from 1983 to 1984; followed by alternate high and low rainy years from 1985 to 1992. After 1992, there was above long-term average between 1993 and 1999, followed by alternate high and low rainy years until 2014. Port Harcourt experienced the highest positive rainfall anomaly index in 2006 and lowest negative rainfall anomaly index in 1983.
The result of the standardized anomaly index for Warri.

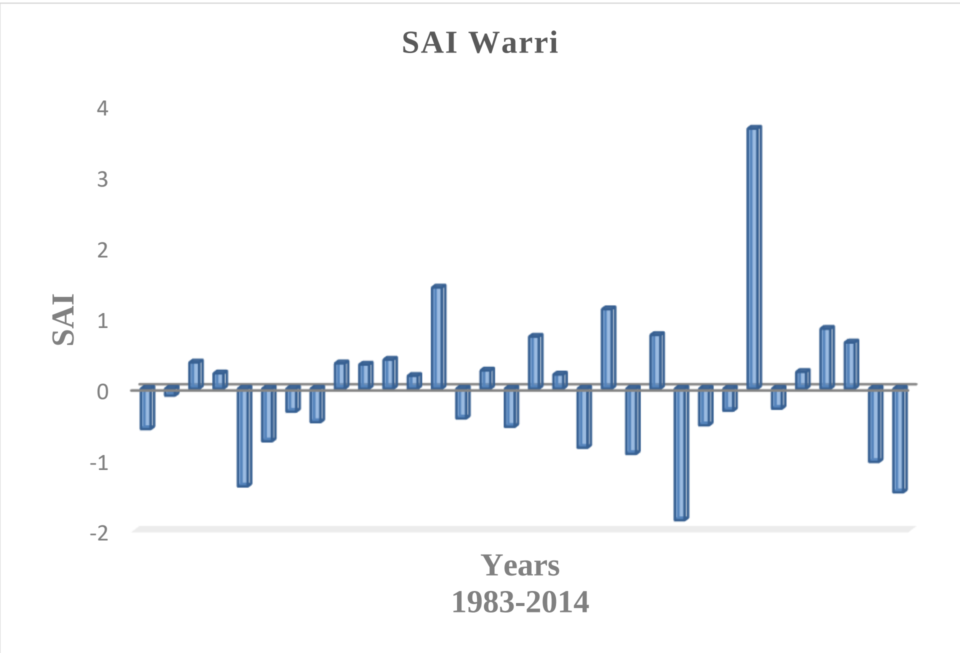

Figure 6. Standardized anomaly index for annual total rainfall at Warri.

Warri experienced below long-term averages annual rainfall during the period spanning 1983 to 1990 with 2 respites of positive anomaly index above average years. From 1991, there was positive departure above average until 1995. From 1996, Warri experienced alternate negative anomaly index below average and positive anomaly index above average until 2014.

Results on trend plots of annual rainfall for the six selected locations

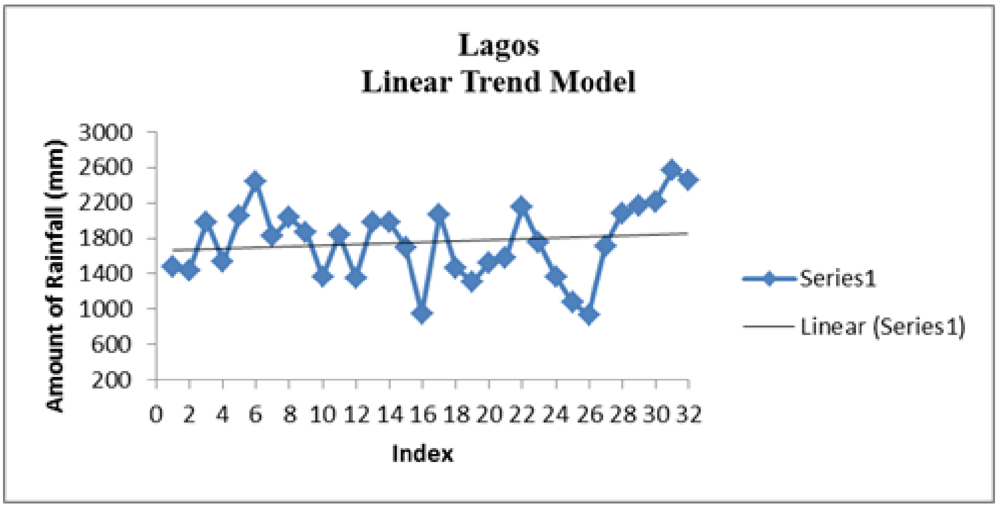

Figure 7. Trend plot of annual rainfall in Lagos.

From the graph the linear trend line is positive, indicating a progressive increase in the annual rainfall during the period of study in the region.

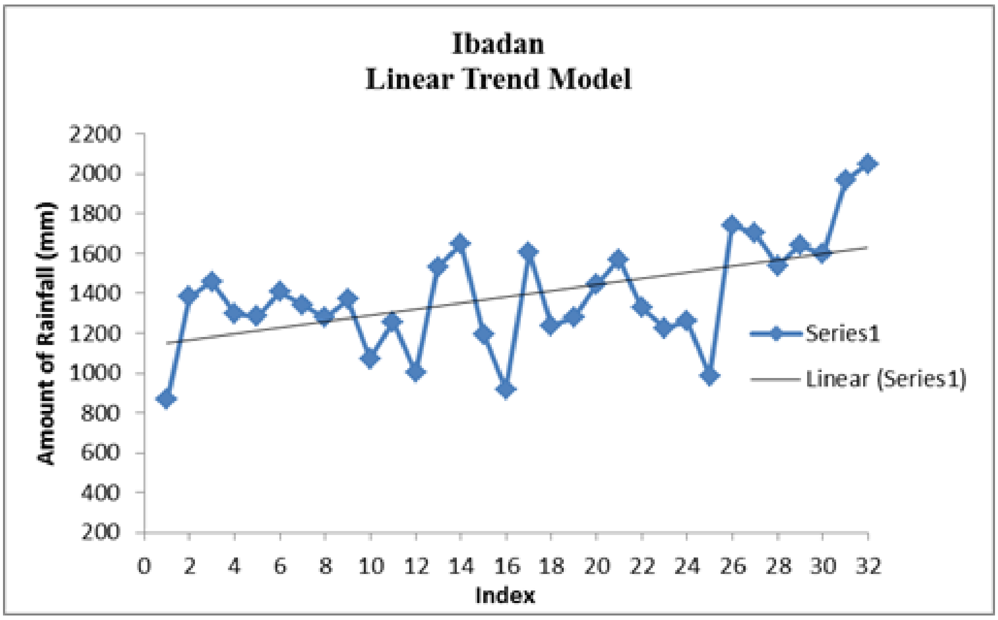

Figure 8. Trend plot of annual rainfall in Ibadan.

From the graph, the trend in rainfall shows a decrease in rainfall as indicated by the decreasing linear trend line. This means that rainfall amount decreases as the years went by.

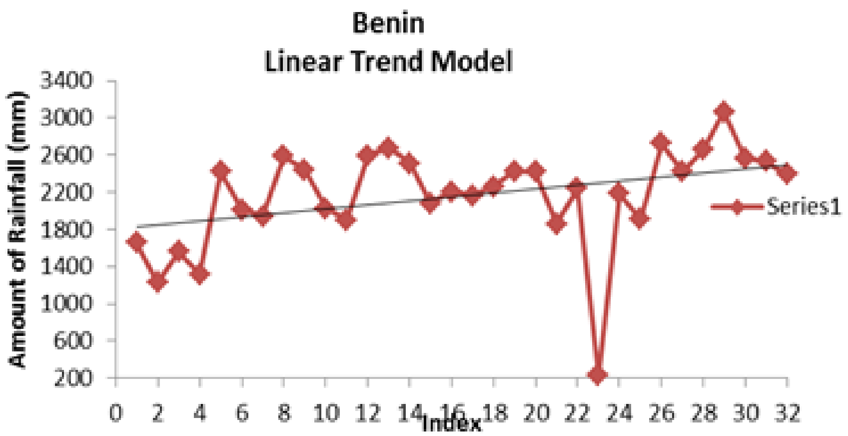

Figure 9. Trend plot of annual rainfall in Benin.

From the graph the linear trend line is positive, indicating a progressive increase in the annual rainfall during the period of study in the study area.

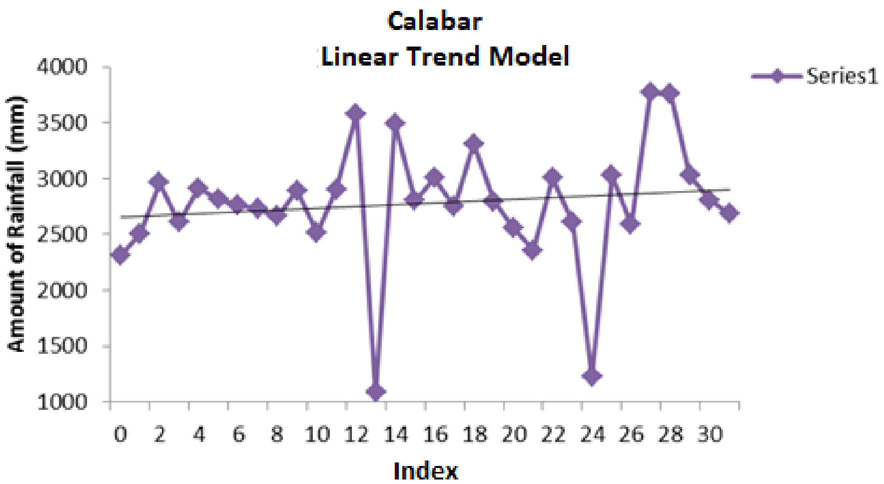

Figure 10. Trend plot of annual rainfall in Calabar.

The graph the linear trend line is positive, indicating a progressive increase in the annual rainfall during the period of study in the study area.

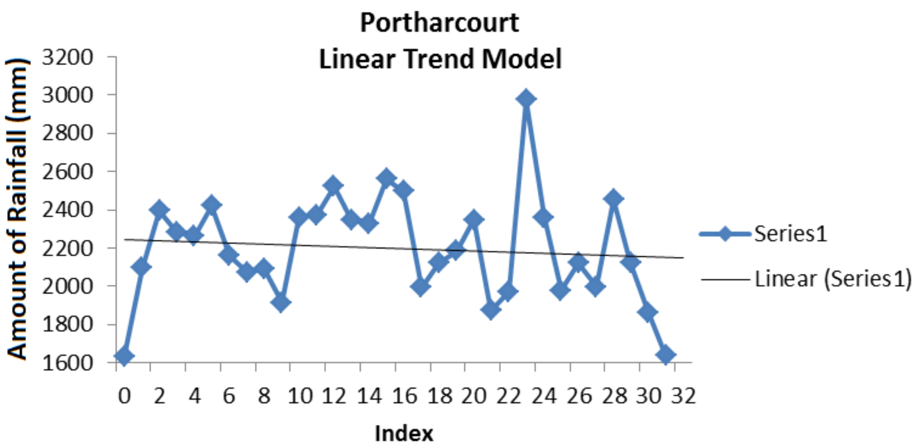

Figure 11. Trend plot of annual rainfall in Port Harcourt.

From the graph, the trend in rainfall shows a decrease in rainfall as indicated by the decreasing linear trend line. This means that rainfall amount decreases as the years went by.

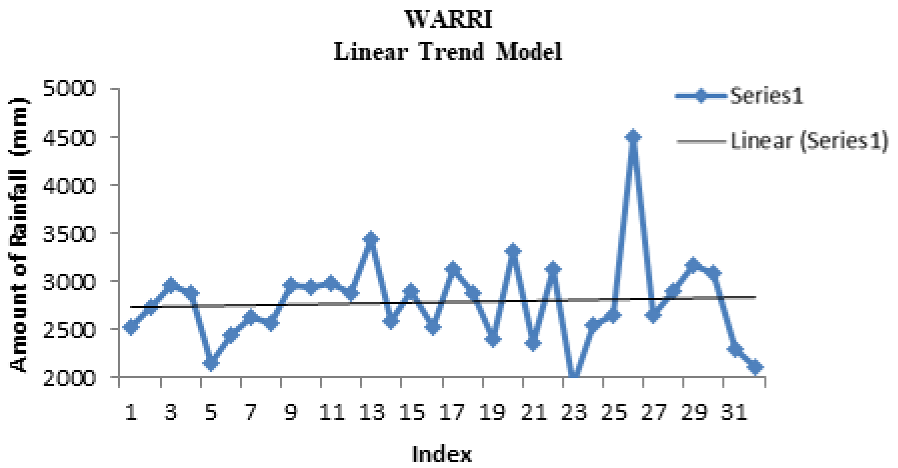

Figure 12. Trend plot of annual rainfall in Warri.

It is evident that the year 2005 recorded the lowest annual rainfall of 1925.8, while the year 2008 recorded the highest rainfall of 4489.80 mm.

Results of Rainfall Intensity Duration Frequency Models and their parameter values
The parameter values used in deriving the Gumbel and Log Pearson Type 111 models, including the models for each region are shown in Table 4.

Table 4: Parameters values used in deriving models for rainfall intensity at different locations.

S/No.	Location	Distribution	Parameters				Models
			a	*b*	*c*	*d*	
1.	Ibadan	Gumbel	108	1.18	0.86	44.18	$I = \frac{108{T_r}^{1.18}}{(t+44.18)^{0.86}}$
		Log Pearson Type III	134	1.26	0.75	36.79	$I = \frac{134{T_r}^{1.26}}{(t+36.79)^{0.75}}$
2.	Benin	Gumbel	131	1.41	0.82	43.53	$I = \frac{131{T_r}^{1.41}}{(t+43.53)^{0.82}}$
		Log Pearson Type III	139	1.64	0.84	40.57	$I = \frac{139{T_r}^{1.64}}{(t+40.57)^{0.84}}$
3	Calabar	Gumbel	442	3.88	1.06	96.04	$I = \frac{442{T_r}^{3.88}}{(t+96.04)^{1.06}}$
		Log Pearson Type III	140	1.57	0.83	43.54	$I = \frac{140{T_r}^{1.57}}{(t+43.54)^{0.83}}$
4.	Lagos	Gumbel	192	1.20	0.72	29.95	$I = \frac{192{T_r}^{1.20}}{(t+29.95)^{0.72}}$
		Log Pearson Type III	149	1.58	0.80	39.37	$I = \frac{149{T_r}^{1.58}}{(t+39.37)^{0.80}}$
5	Port-Harcourt	Gumbel	135	1.72	0.83	46.35	$I = \frac{135{T_r}^{1.72}}{(t+46.35)^{0.83}}$
		Log Pearson Type III	140	1.23	0.73	30.33	$I = \frac{140{T_r}^{1.23}}{(t+30.33)^{0.73}}$
6.	Warri	Gumbel	136	1.50	0.79	39.18	$I = \frac{136{T_r}^{1.50}}{(t+39.18)^{0.79}}$
		Log Pearson Type III	148	1.36	0.77	34.94	$I = \frac{148{T_r}^{1.36}}{(t+34.94)^{0.77}}$

Table 4 shows the different models derived for the estimation of future trends in rainfall in the study area and beyond.

CONCLUSION

This research indicates the procedure for the development of precipitation (rainfall) intensity duration frequency models for selected locations in humid forest zones of Nigeria. The studied locations are Lagos, Ibadan, Benin, Calabar, Port Harcourt and Warri in Nigeria. The study also surveyed tendencies and fluctuations in rainfall, rainfall anomaly index and significant variations in rainfall pattern of the locations under investigation. The trend analysis result shows obvious fluctuating precipitation pattern across the observed years. This has made it impossible to forecast the precipitation for a feature season. The following conclusions and recommendation were drawn from the study; the climate of the studied regions shows precipitation characterized by alternating wet and dry periods. Rainfall and temperature are the core variables that enhance human well- being, plant growth and crop production etc. Incessant variation in rainfall pattern might result to unfavorable growth conditions and thereby enhances the breeding of anopheles mosquitoes, which in turn causes malaria. To achieve adequate climate forecasting capacity, the study therefore recommends that qualitative climatic data which should be made available and accessible for easy analysis and for future prediction a valuable model was derived to enhance researchers who may want to estimate the precipitation trends in Nigeria and the world.

DECLARATION OF COMPETING INTEREST

Authors hereby declare that there is no conflicting of interest whatsoever.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors hereby declare that the contributions given are correct.
Cordella Chika Emeka-Chris: Writing original draft and statistical review.
Christopher Ikechi Obineche: Validation, review and methodology.
Bejoy Otuobi Unanka: Investigation and preview.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1170683

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 292-307

Research Article

Assessment of Soil Physico-Chemical Properties on a Toposequence of an Erosion Site in Ikeduru, Southeastern Nigeria

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ABSTRACT

The study was carried out to assess soil physic-chemical properties of an erosion site in Ikeduru, Imo State Nigeria, which has experienced land degradation over the years. Three profile pits were dug, described and samples collected for the physico-chemical laboratory analysis. Data obtained were analyzed using Genstat Discovery, Edition 4 for a CRD experiment. The outcome shows soils was deep, fine weak, dark brown, brown, red and dark reddish brown in the Munsell colour code. An LSD, a correlation at 5% probability level was used to separate the means significantly. Correlation investigation was carried out to explain relationships among selected physico-chemical properties of the studied soil. The particle size distribution indicated high sand content and low clay content in the three profiles selected with SCL as dominating textural class, except for 1.85 g cm^{-3} bulk density which was observed to be safe in all the profile pits examined, the silt – clay ratio was low (<1), except at the surface soil in the foot-slope (1.09). Soil pH (KCl) was moderately acidic at the summit. The organic matter had significant positive correlations with TN (r = 0.99***), Ca (r = 0.85**), Mg (r = 0.59*), K (r = 0.61*) and ECEC (r = 0.74**). Phosphorus maintained significant positive relationships with all basic cations with correlation coefficients that ranged from 0.51* for K to 0.59* for Ca. Total exchangeable acidity had a significant (P<0.001) negative relationship with %BS (r =-0.98***). It has been seen that the main causes of erosion are unprofessional land use forms.

RESEARCH ARTICLE

Received: 04.09.2022
Accepted: 16.11.2022

Keywords:

- Particle size distribution,
- Soil erosion,
- Soil properties,
- Soil texture, toposequence

To cite: Oriako, PA, Obineche, CI, Ezechike NU and Ezema PC (2022). Assessment of Soil Physico-Chemical Properties on a Toposequence of an Erosion Site in Ikeduru, Southeastern Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 292-307.*
https://doi.org/10.46592/turkager.1170683

INTRODUCTION

Soil erosion has been a challenging factor in the southeastern part of Nigeria where vast lands are being affected, causing transposition of topsoils, hence; causing the degrading of soil. Water and wind are found to be the major agents of soil erosion and land degradation; each contributes to a substantial extent of soil loss annually. The loss of topsoil from farmland could be reproduced in deficit crop production potential, lesser shallow water quality and spoiled drainage systems (Morgan, 1991). Agricultural production, sustenance and management aimed at food safety and sustenance have been greatly undermined in this section by the threat postured by soil destruction although the accessibility of agricultural farmlands for production and construction events has been significantly minimized by the losses initiated by the associated problems with soil erosion (Okorafor *et al.*, 2017).

The erosion of soils is seen as a major ecological difficulty as it utterly threatens and destroys natural resources as well as the environment (Rahman *et al.*, 2009). Soil erosion diminishes soil quality and reduces the productivity of natural, agricultural and forest ecosystems (Pimentel, 2006). Water and wind erosion are the two major constituents of land degradation: water and wind erosion cause 84% of te global magnitude of degraded land mass, excessive erosion, and most notable environmental defects (Mbagwu, 1996). Soil characterization is an essential part of the determination of the nature and extent of soils on a construction site or earth system in order to review subsurface conditions and ensure that the soil composition adhere to any lead down regulations. Soil contamination, soil or land pollution as part of land degradation is caused by the presence of human–made chemicals or other alteration in the natural soil environment (Wikipedia, 2022). Depth characterization also provides a key parameter in determining volumes of contaminated soil. Recently El- Swaify (1994) observed that the third world countries suffer from soil degradation incurred due to the maladministration of land; this has posed a main distress that threatens pastoral growth and economy. According to Wang and Gong (1998) one of the major factors that enhance the global biosphere and agricultural development practice is the quality of soil. To develop a workable soil management practice that will ensure the great productive potential of a soil, the knowledge of basic soil properties is required. The study is accurate of the temperate topsoil with intrinsic characteristics which include low (water holding capacity, cation exchange capacity, organic matter content) structural variability and flood hazard especially at foot slopes hence; it creates an uneven environment which envelops to soil erosion. Therefore, there is a need to characterize some of these problems on a toposequence and proffer solutions. The study's objectives are to compare soil physical-chemical properties of a toposequence in an erosion-prone environment, determine the effect of erosion on soil quality in the environment, and propose potential solutions to reduce the threat of soil erosion to agricultural productivity improvement.

MATERIALS and METHODS

Ikeduru Local Government region is situated in the western part of Imo State in Southeastern Nigeria. It is located on latitude 5° 56" 795' N, longitudes 7° 15" 338' E and with altitude of about 150 m (492 ft) and a monsoon climate. The area has mean annual rainfall ranging from 2000 mm to 2500 mm, a mean temperature of 27°C and humidity of between 70% and 80%. The climatic condition of the area favours the production of vegetables (pumpkin leaf) cassava, pineapple and plantains.

Geology of the workspace

The geological material from which the soils of the study area developed is coastal plain sand (Benin formation). The landform of the study area is dominated by gentle rolling relief which stretch towards a plain usually with streams that govern the hydrology of the area. The toposequence has a slope characterized by three identifiable units namely the upper-slope, mid- slope and foot-slope. The slope is 9% (upper-slope), 5% (mid-slope) and 2% (foot-slope). The slope was obtained using Abney level (Juo and Moorman, 2000). A humid tropical climate with an average annual rainfall of about 2156 mm and annual temperature of about 26°C and high relative humidity of 75% (Esu *et al.*, 2008).

Field work and sample collection

Transect survey technique was employed in aligning soil profile pits along the slope. The collected samples were described according to FAO (2006). The location of the profile pits was done based on the accessible land usage as seen in the region, by way of augering along the topo-sequence the soil distribution as well as the topography of the area were determined. Three profile pits with designation: ECH/UK/01 (Summit), ECH/UK/02 (Middle slope), and ECH/UK/03 (Footslope) were placed end to end on the slope. Three samples of soil type were collected and characterized with respect to depth, 01: 0 – 30, 30 – 45, 45 – 65, 65 – 85, 85 – 110 cm, 02: 0 – 20, 20 – 40, 40 – 65. 65 – 85, 85 – 120 cm and 03: 0 – 15, 15 – 30, 30 – 45, 45 – 60, 60 – 100 cm. Samples collected were bagged, branded and conveyed to the laboratory for proper investigation.

Laboratory analysis

The samples of the soil were analyzed for certain selected soil properties that are necessary for proper scientific classification of the soils. The selected physical properties as determined includes particle size distribution, bulk density, moisture content and chemical properties including soil pH, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), exchangeable acidity (Al^{3+} and H^+), total nitrogen, available phosphorus and organic carbon.

The particle size distribution was determined through hydrometer method agreeing to the technique of Gee and Or (2002). Bulk density determined via core method (Grossman and Reinsch, 2002). Moisture content is determined gravimetrically by oven-drying saturated soil samples 105°C within 24 hours, as well as moisture percentage calculated (Obi, 1990). Thomas (1996), 1: 2.5 soil-liquid ration using pH meter was used to determine the soil pH.

Organic carbon was determined by wet digestion method (Nelson and Sommers, 1982). Total nitrogen was determined by micro Kjeldahl distillation method (Bremmer and Mulvaney, 1982). Bray 11 method as described by Olsen and Sommers (1982) was used to determine the available phosphorus content. EDTA complexometric titration was used to obtain calcium and magnesium while an NH_4OA_C solution was used to extract the exchangeable basic cation. Exchangeable potassium and sodium were evaluated by means of flame photometry (Jackson, 1973).

According to McLean (1992) exchangeable acidity determination was carried out titrametrically through the extraction of exchangeable H^+ and Al^{3+} with in potassium chloride. The calculation of *ECEC* (Effective Cation Exchange Capacity) was done via summing up the value of the basic cations in cmol kg^{-1}. Percentage base saturation was calculated thus;

$$\%BS = \frac{TEB}{ECEC} \times \frac{100}{1} \tag{1}$$

Where,
BS: Base Saturation
TEB: Total Exchangeable Base cmol kg^{-1}
ECEC: Effective Cation Exchange Capacity

Aluminum saturation was calculated thus;

$$AL\ sat = \frac{AL^{3+} Cmol/\ kg\ sn^{1}}{ECEC\ Cmol/kg} \times \frac{100}{1} \tag{2}$$

Where,
Al sat: Aluminum Saturation
ECEC: Effective Cation Exchange Capacity
cmol: Centimole

Data and statistical analysis

Analysis of variance (ANOVA) for a CRD experiment was used in analyzing the data using SAS Package. Significant treatment means were separated using Least Significant Difference (LSD) at 5% probability level. Pearson correlation analysis was used to determine the relationships between measured variables.

RESULTS AND DISCUSSION

The soils morphological characteristics are shown in Table 1. The horizons were well-drained except for the horizons that shared boundary with the high water table at the footslope. This is due to the texture and structure of the soils geography of the study area. The trend of the particle size distribution down the profile was responsible for the loose and firm consistency of the soil both surface and sub-surface respectively. The structure and sandy nature of the soils explain why the soils were generally well drained and susceptible to leaching and erosion.

The various physiographic positions have different colour matrix range which are described as follows; at the summit it was observed that across the horizons the colour ranges from Brown (7.5YR$^4/_3$) when moist to Red (2.5YR $^4/_8$) when moist. The midslope recorded a colour range of Brown (7.5YR $^4/_2$) when moist to Red (2.5 YR $^4/_8$).

Furthermore, the footslope had colour matrix range, Brown (7.5 YR $^4/_2$) when moist, when moist and Red (7.5 YR ^{4}/4) when moist. The drainage condition and physiographic position may have influenced the observable changes in the soil colour matrix in topographic units.

However, the textural class of the toposequence ranges from sandy loam to sandy clay loam. The slope showed a textural range of sandy loam (SL) at the A horizon, and sandy clay loam (SCL) was observed at other horizons for the summit. The midslope shows a textural range of A, B1 & B2 horizons and sandy clay loam (SCL) at the B_3 and C horizon. The footslope was observed to have a textural range of sandy loam (SL) at A and B_1 horizon.

Table 1. Morphological characteristics of soils of the study site.

Slope Gradient	Depth (cm)	Matrix colour (moist)	Texture	Structure	Consistency	Drainage	Root
Summit							
	0-30	Brown (7.5YR $^4/_3$)	SL	Granular	Loose	Wd	Mf
	30-45	Dark Reddish Brown (2.5 YR $^3/_3$)	SCL	Sbk	Firm	Wd	Mf
	45-65	Reddish Brown (2.5R $^4/_4$)	SCL	Sbk	Firm	Wd	Mf
	65-85	Reddish Brown (2.5R $^4/_4$)	SCL	Sbk	Firm	Wd	Cf
	85-110	Red (2.5 $^4/_8$)	SCL	Sbk	Firm	Wd	Cf
Midslope							
	0-20	Brown (7.5YR $^4/_2$)	SL	Granular	Loose	Wd	Mf
	20-40	Dark Reddish Brown (5YR $^3/_2$)	SL	Sbk	Firm	Wd	Mf
	40-63	Dark Reddish Brown (2.5YR $^3/_4$)	SL	Sbk	Firm	Wd	Mf
	63-80	Dark Reddish Brown (2.5YR $^3/_6$)	SCL	Sbk	Firm	Wd	Cf
	80-120	Red Brown (2.5YR $^4/_8$)	SCL	Sbk	Firm	Wd	Fine
Footslope							
	0-15	Dark Brown (5YR ¾)	SL	Crumb	Loose	Wd	Mf
	15-30	Reddish Brown (5YR $^4/_4$)	SL	Sbk	Firm	Wd	Mf
	30-45	Reddish Brown (2.5YR $^4/_4$)	SCL	Sbk	Firm	Wd	Cf
	45-60	Dark Brown (5YR $^4/_6$)	SCL	Sbk	Firm	Wd	Cf
	60-100	Dusky red (7.5YR $^4/_4$)	SCL	Sbk	Firm	Pd	Fine

YR = Yellow-red, SL = Sandy loam, SCL = Sandy clay loam, Sbk = Subangular blocky, Wd = Well drained, Pd = Poorly drained, Mf = Many fine, Cf = Common fine, F = Fine

Soil physical properties

Tables 2 and 3 posits the soil results of the physic-chemical properties and are stated as Pedons Summit via Mid-slope plus Foot-slope, hence the distinctions in the physical and chemical properties in different soil profile depths (Summit), (Midslope), and (Footslope), while Table 4 shows the mean variation value of physico-chemical properties in varying toposequence.

Particle size distribution of soil texture

The comparative percentage of the different soil such as sand, silt, and clay which makeup the classes of soil (Gee and Or, 2002). Hence, the outcome shows that the content of the sand in all the samples was actual high and it ranges from 66.8 - 80.8%, while Summit and Foot-slope obtained 85% which is the maximum outcome and Mid-slope (67 %) which is the least.

Low silt content was recorded in all the profiles in the pedons ranging from 2.0 – 10.0. Low to medium ranged of 2.0-6.2% was observed in the clay contents. Summit and foot-slope recorded maximum values, however displays no convincing development. The clay movement with other finer materials results from top amid shows 8.2 – 27.2% that fluctuates among the depths of all soils by an overland flow, the results was in line with Akamigbo (1999) and Adekayode and Akomolafe (2011). As posit by Medugu *et al.* (2008) the issue could be resolved by tree planting to protect the soil from being eroded.

Bulk density

Gee and Or (2002) defines bulk density as dry weight (mass) of the soil over unit of bulk volume of soil. The bulk densities of soil samples are usually moderate, ranging between 1.50 and 1.70 g cm^{-3}. According to De Geus (1973), bulk densities greater than 1.75 g cm^{-3} for sands limit root penetration in soils.

Table 2. Soil physical properties of erosion prone toposequence

Slope Gradient	Horizon depth (cm)	Sand (%)	Silt (%)	Clay (%)	Silt/Clay ratio	TP (%)	Bd (g cm^{-3})	Texture
Summit	0 – 30	80.8	2.0	17.2	0.12	43.40	1.50	SL
	30 – 45	70.8	2.0	27.2	0.07	43.40	1.50	SCL
	45 – 65	70.8	2.0	27.2	0.07	43.40	1.50	SCL
	65 – 85	66.8	2.0	31.2	0.06	43.40	1.50	SCL
	85 – 110	68.8	2.0	29.2	0.07	43.40	1.50	SCL
Mean		**71.6**	**2.0**	**26.4**	**0.08**	**43.40**	**1.50**	
Mid slope	0 – 20	76.8	4.0	19.2	0.21	44.15	1.48	SL
	20 – 40	89.8	2.0	8.2	0.24	43.40	1.50	SL
	40 – 63	76.8	4.0	19.2	0.21	39.62	1.60	SL
	63 – 80	76.8	2.0	21.2	0.09	43.40	1.56	SCL
	80 – 120	72.8	2.0	25.2	0.08	43.40	1.60	SCL
Mean		**78.6**	**2.8**	**18.6**	**0.17**	**41.58**	**1.55**	
Foot slope	0 – 15	80.8	10.0	9.2	1.09	43.40	1.50	SL
	15 – 30	78.8	8.0	13.2	0.61	43.40	1.50	SL
	30 – 45	68.8	5.0	26.2	0.19	41.51	1.55	SCL
	45 – 60	78.8	4.0	17.2	0.23	39.62	1.60	SCL
	60 – 85	70.8	4.0	25.2	0.16	39.62	1.60	SCL
Mean		**75.6**	**6.2**	**18.2**	**0.46**	**41.51**	**1.56**	
LSD (0.05)		**NS**	**2.2****	**7.1***	**NS**	**NS**	**NS**	

*, ** = Significant at 5 and 1% probability levels, respectively; NS = Not significant at 5% probability level.
SL = Sandy loam; SCL = Sandy clay loam.

Silt / Clay ratio

A silt / clay ratio at the topsoil level is a soil index used to assess flood risk. Where the ratio is <1, it suggests absence of flood hazard in the environment. However, when the ratio is >1, it suggests presence of flood incidence/hazard. Results obtained from this study showed that Silt/clay ratio at 0-30 cm soil depth at the summit and at 0-20 cm at mid-slope were <1 (0.12, and 0.21, respectively) (Table 2), hence; it agrees with Nwosu *et al.* (2011) who noted that such soils are old and highly weathered. Silt /clay ratio at the foot-slope was greater than 1, suggesting flood hazard at 0 – 15 cm soil depth at the foot-slope.

Soil chemical properties

The outcomes of toposequence of an erosion prone area on soil chemical properties are as shown in Table 3.

Soil pH

The pH of the soil indicates strongly acidic in the absence of potassium chloride; while the pH of the soil alternates between 4.08 and 4.66, this indicates high level acidity content; however, in one horizon of the mid-slope, the range falls within 4.9, indicating that the acidic response is very strong as shown in (Table 3). The pH value a times increases with the depth as noted by Yakubu and Ojanuga (2011) and Sharu *et al.* (2013) who reported that the average pH values of the soils are 7.7, 7.1 and 7.0 which indicates acidity of the soil around humid regions. While, Akamigbo and Igwe (1990) who noted that low acidity result are observed in soils around humid regions due to soil erosion that is liable for the low to high calcium and magnesium contents of the soil.

Soil organic carbon (OC) and soil organic matter (OM)

The summit has an OM range of 0.38 1.17%, the mid-slope has an OM range 0.14 1.10% and foot-slope and organic matter alternate between 0.10 and 0.93%. According to Morgan (1991) the outcomes are consistent hence it is in line with the organic (matter and carbon) in tropical soils as they are mostly low owing to leaching activities and terrible sheet erosion, accompanied by the burial of top soils via tillage operation with mineralization of organic matter via increased warmth.

Total nitrogen

The outcomes of the total nitrogen content in the three Summit, Mid-slope and Foot-slope indicates values alternate amid 0.02-0.12 %, 0.01-0.06 %, 0.01-0.05% separately. There was a decrease in nitrogen values of the soil with increased depth, caused by the erosion of nitrates on the top soils. This is in line with Noma *et al.* (2011) who noted that Total Nitrogen values of the soils in the area changed irregularly with depth which could be attributed to influence of continuous land use and degradation in the area. Esu (1991) the Total Nitrogen in the soils remained low when compared to the evaluations.

Available Phosphorus (AvP)

The result of the available phosphorus content of the soil (0.25-2.65 cmol kg^{-1}) hence, pedon 01 has values from 1.1-1.25 cmol kg^{-1}, mid-slope varied between 0.28-0.50 cmol kg^{-1} and Foot-slope varied between 1.00-2.25 cmol kg^{-1}. The values are comparable with the values reported by Ohaeri and Eshett (2011). The loss of phosphorus is commonly owing to its elimination by the crops as posit by (Enwezor *et al.*, 1990). Phosphorus react in acidic soils to produce an insoluble compounds such as Fe^{3+}, Al^{3+}, and Mg^{2+}

Exchangeable bases

The results of the exchangeable bases show that sodium (Na^+) has 0.11-0.16 cmol kg^{-1}, potassium (K^+) 0.12-0.17 cmol kg^{-1}, magnesium (Mg^{2+}) 0.18-1.48 cmol kg^{-1} and calcium (Ca^{++}) has 1.22-1.86 cmol kg^{-1} in pedon 01. As noted by Esu et al (2008) the results show values from low to medium in all pedon. The result of the study was supported by Noma *et al.* (2004) who noted that the exchangeable bases are generally low, showing it was inconsistent. This was in accordance Mbagwu (1996) who stated that the leaching of Ca and Mn is principally liable in the growth of acidity in the soil through high precipitation via permeable layer of the soil texture in addition to the parent constituents.

Total Exchangeable Acidity (TEA)

The results of the total exchangeable acidity (0.3-1.1 cmol kg^{-1}) show that total exchangeable acidity falls in the middle of low and medium with higher values noted in the Summit and Mid-slope, as well as the Foot-slope which has the poorest outcome. Note that TEA is the measurement of the quantity of cation exchange capacity content in the soil which is occupied by acidic cations.

Effective Cation Exchangeable Capacity (ECEC)

The results of ECEC obtained in Table 3; indicate an observation of low to medium values which falls between 3.50 and 3.87 cmol kg^{-1}. The highest value was found in Summit, while the lowest in Foot-slope. It will be noted that due to the activities of clay mineral content (kaolinite) the value of ECEC turned low.

Base Saturation (BS)

The BS results as obtained were very high going from 71.87-90.00%, the highest value was observed in Summit in the lowest horizon, while the Mid-slope observed the lowest outcome in the upper horizon. The figure obtained is in consonance with Akamigbo and Asadu (1986), who posit that parent constituents may have a sturdy control on the total exchangeable bases as well as the total acidity of a soil; which may be due to erosion of soil by precipitation.

Table 3. Soil chemical properties of an erosion prone toposequence.

Toposequence	Horizon depth (cm)	pH (H_2O)	pH (KCl)	OM (%)	TN (%)	Av. P (mg kg^{-1})	TEA	Ca^{2+}	Mg^{2+}	K^+	Na^+	ECEC	%BS
							→		cmol kg^{-1}	←			
Summit	0 – 30	5.10	4.42	2.31	0.12	1.1	0.4	1.86	1.42	0.17	0.15	4	90.00
Summit	30 – 45	4.66	4.32	1.17	0.06	1.25	1.0	1.67	1.44	0.15	0.13	4.39	77.22
Summit	45 – 65	4.93	4.35	0.59	0.03	1.15	1.1	1.28	1.26	0.14	0.13	3.91	71.87
Summit	65 – 85	5.19	4.60	0.55	0.03	0.00	0.9	1.26	1.20	0.12	0.11	3.59	74.93
Summit	85 – 110	4.98	4.31	0.38	0.02	0.00	0.7	1.22	1.28	0.13	0.14	3.47	79.83
Summit mean		**4.97**	**4.40**	**1.00**	**0.05**	**0.70**	**0.82**	**1.46**	**1.32**	**0.142**	**0.132**	**3.87**	**78.77**
Mid slope	0 – 20	4.37	4.10	1.10	0.06	0.5	1.1	1.4	1.36	0.14	0.13	4.13	73.37
Mid slope	20 – 40	4.86	4.08	1.00	0.05	0.45	1.0	1.45	1.23	0.14	0.15	3.97	74.81
Mid slope	40 – 63	5.09	4.45	0.14	0.01	0.00	0.7	1.36	1.28	0.15	0.12	3.61	80.61
Mid slope	63 – 80	5.17	4.66	0.00	0.00	0.00	0.5	1.29	1.22	0.13	0.13	3.27	84.71
Mid slope	80 – 120	4.48	4.17	0.00	0.00	0.45	0.8	1.27	1.24	0.14	0.12	3.57	77.59
Mid slope mean		**4.79**	**4.29**	**0.45**	**0.02**	**0.28**	**0.82**	**1.35**	**1.27**	**0.140**	**0.130**	**3.71**	**78.22**
Foot slope	0 – 15	5.22	4.61	0.93	0.05	2.65	0.3	1.6	1.48	0.16	0.15	3.69	91.87
Foot slope	15 – 30	4.98	4.15	0.34	0.02	1.00	0.6	1.43	1.3	0.14	0.16	3.63	83.47
Foot slope	30 – 45	5.09	4.52	0.10	0.01	1.00	0.5	1.38	1.18	0.15	0.14	3.35	85.07
Foot slope	45 – 60	4.43	4.56	0.17	0.01	1.15	0.6	1.24	1.34	0.12	0.15	3.45	82.61
Foot slope	60 – 85	4.87	4.60	0.34	0.02	0.00	0.4	1.32	1.38	0.14	0.13	3.37	88.13
Foot slope mean		**4.92**	**4.49**	**0.38**	**0.02**	**1.16**	**0.48**	**1.39**	**1.34**	**0.140**	**0.150**	**3.50**	**86.23**
Toposequence LSD (0.05)		NS	NS	0.45*	0,02*	NS	NS	NS	NS	NS	NS	0.27*	NS

* = Significant at 5% probability level; NS = Not significant at 5% probability level.
OC =organic content, OM= organic matter, TN= total nitrogen, TEA=total exchangeable acidity, AL= aluminum, H= hydrogen,
Ca= calcium, Mg= magnesium, potassium, Na= sodium, TEB= total exchangeable base, CEC= cation exchangeable capacity, BS=base saturation,
Avl. P = available phosphorus

Variation of selected soil properties within profile depths

Table 4 shows the level of variability of some selected properties within profile depths. There was low variation of soil pH (KCl) within the profile irrespective of physiographic position on the toposequence. Other parameters with low variation within the profile at all the physiographic units on the toposequence include sand, potassium, calcium, total exchangeable acidity and base saturation. This agrees with Ogunkunle (1993) that soil pH and porosity (sand) are the least variable soil properties.

Clay varied moderately at the summit but only slightly at the mid-slope and foot-slope. Effective cation exchange capacity showed differential variations across the toposequence, being high, moderate and low at summit, mid-slope and foot-slope, respectively. This could be attributed to the impact of erosion along the toposequence. At the summit, the percent silt showed no variation. However, there was moderate variation at mid-slope and foot-slope. This could be attributed to alluvium and colluvium deposition at these physiographic units.

There was high variation of organic matter within the profile in all the physiographic position on the toposequence. This can be ascribed to the differential loss of organic matter caused by erosion commencing from the summit to the foot-slope.

Table 4. Selected soil properties within profile depth with rankings.

Soil properties	Summit		Mid-slope		Foot-slope	
	Means/Std	Ranking*	Means/Std	Ranking	Means/Std	Ranking
Sand	71.6±5.4	Lv	78.6±6.5	Lv	75.6±5.4	Lv
Silt	2.0±0.0	Nv	2.8±1.1	Mv	6.2±2.7	Mv
Clay	26.4±5.4	Mv	18.6±6.3	Lv	18.2±7.4	Lv
BD	1.5±0.00	Nv	1.55±0.06	Lv	1.56±0.05	Lv
TP	43.40±0.00	Nv	41.58±2.11	Lv	41.51±1.89	Lv
pH(KCl)	4.40±0.12	Lv	4.29±0.29	Lv	4.49±0.19	Lv
K	0.142±0.02	Lv	0.140±0.01	Lv	0.140±0.01	Lv
Ca	1.46±0.29	Lv	1.35±0.08	Lv	1.39±0.14	Lv
TEA	0.82±0.28	Lv	0.82±0.24	Lv	0.48±0.13	Lv
ECEC	3.87±0.36	Hv	3.71±0.34	Mv	3.50±0.15	Lv
OM	1.00±0.79	Hv	0.45±0.55	Hv	0.38±0.33	Hv
BS	78.77±6.93	Lv	78.22±4.57	Lv	86.23±3.79	Lv

Ranking*: Hv= High variation; Mv = Medium variation; Lv = Low variation; and Nv = No variation.

Relationship among soil properties

Pearson correlation analysis was carried out to obtain relationships that exist between selected soil properties of a toposequence of erosion area. The results are as shown in Table 5. Percent sand recorded a very significant negative correlation with percentage clay (r = 0.98***). This is as expected as an increase in sand content will bring about a decrease in clay content of the soil. Silt had a non-significant positive or negative correlation with all measured soil parameters, with correlation coefficients that ranged from 0.06^{ns}-0.27^{ns}. A rise in the soil's clay content decreased the soil sodium content studied (r =-0.67**). This relationship reinforces the opposite roles of clay and sodium as flocculating and deflocculating agents in soil management, respectively. However, an increase in sand content maintained a positive and significant ($p<0.01$) increase in soil sodium (r =-0.67**).

Bulk density had a significant inverse relationship with OM (-0.62*), TN (-0.62*) and ECEC (-0.61*). Low soil OM increases soil compaction which increases soil BD. This relationship may be linked with the role of OM in increasing soil TN and ECEC with increase in OM.

Soil reaction (pH) in KCl had a negative and significant ($P<0.05$) correlation with TEA and ECEC (r = 0.62* and r = 0.55*, respectively and a positive and significant ($P<0.05$) correlation with percent base saturation (%BS) (r = 0.56*). Organic matter had significant positive correlations with TN (r = 0.99***), Ca (r = 0.85**), Mg (r = 0.59*), K (r = 0.61*) and ECEC (r = 0.74**). This relationship of OM with TN, basic cations and ECEC underscores the importance of OM as an index of soil fertility management. Similar effects were recorded in the relationships between soil TN and Ca (0.86***), Mg (r = 0.60*), K (r = 0.63* and ECEC (r = 0.73**). These, support the assertion that a degraded Ultisol with low TN will most likely be low in Ca, Mg, K and ECEC. Calcium content in the studied soils accounted for 84% and 66% soil exchangeable K and Mg contents of the soils, respectively (r = 0.84*** and r = 0.66**, respectively).

Phosphorus maintained significant positive relationships with all basic cations with correlation coefficients that ranged from 0.51* for K to 0.59* for Ca. This suggests that an improvement in soil P of the studied soil will equally improve basic cations in the soil. Total exchangeable acidity had a significant ($P<0.001$) negative relationship with %BS (r =-0.98***). This is as expected in an acidic soil, where an increase in TEA will bring about a decrease in %BS.

Table 5. Pearson correlation analysis of selected soil properties of a toposequence

Soil property	Sand %	Silt %	Clay %	BD g cm^{-3}	TP %	pH (KCl)	OM %	TN %	Ca cmol kg^{-1}	Mg cmol kg^{-1}	K cmol kg^{-1}	Na cmol kg^{-1}	TEA cmol kg^{-1}	ECEC cmol kg^{-1}	BS %	P mg kg^{-1}
Sand	1															
Silt	-0.08^{ns}	1														
Clay	-0.98***	-0.12^{ns}	1													
BD	-0.13^{ns}	0.29^{ns}	0.08^{ns}	1												
TP	0.13^{ns}	-0.29^{ns}	-0.08^{ns}	-1.0***	1											
pH (KCl)	-0.29^{ns}	0.11^{ns}	0.27^{ns}	0.37^{ns}	-0.37^{ns}	1										
OM	0.34^{ns}	-0.27^{ns}	-0.28^{ns}	-0.62*	0.62*	-0.21^{ns}	1									
TN	0.33^{ns}	-0.23^{ns}	-0.28^{ns}	-0.62*	0.62*	-0.20^{ns}	0.99***	1								
Ca	0.42^{ns}	-0.17^{ns}	-0.38^{ns}	-0.42^{ns}	0.42^{ns}	-0.09^{ns}	0.85***	0.86***	1							
Mg	0.24^{ns}	-0.25^{ns}	-0.19^{ns}	-0.19^{ns}	0.19^{ns}	0.07^{ns}	0.59*	0.60*	0.66*	1						
K	0.32^{ns}	0.03^{ns}	-0.33^{ns}	-0.20^{ns}	0.20^{ns}	-0.08^{ns}	0.61*	0.63*	0.84***	0.53*	1					
Na	0.67**	0.00^{ns}	-0.67**	-0.27^{ns}	0.27^{ns}	-0.19^{ns}	0.30^{ns}	0.30^{ns}	0.40^{ns}	0.34^{ns}	0.29^{ns}	1				
TEA	-0.16^{ns}	-0.06^{ns}	0.17^{ns}	-0.36^{ns}	0.36^{ns}	-0.62*	0.06^{ns}	0.04^{ns}	-0.22^{ns}	-0.27^{ns}	-0.32^{ns}	-0.39^{ns}	1			
ECEC	0.21^{ns}	-0.21^{ns}	-0.17^{ns}	-0.61*	0.61*	-0.55*	0.74**	0.73**	0.62*	0.47^{ns}	0.41^{ns}	0.05^{ns}	0.60*	1		
BS	0.24^{ns}	0.03^{ns}	-0.24^{ns}	0.26^{ns}	-0.26^{ns}	0.56*	0.11^{ns}	0.13^{ns}	0.41^{ns}	0.44^{ns}	0.47^{ns}	0.46^{ns}	-0.98***	-0.41^{ns}	1	
P	0.35^{ns}	0.01^{ns}	-0.35^{ns}	-0.31^{ns}	0.31^{ns}	0.07^{ns}	0.36^{ns}	0.37^{ns}	0.54*	0.59*	0.51*	0.55*	-0.24^{ns}	0.32^{ns}	0.36^{ns}	1

*; **; *** = Significant at 5, 1 and 0.1% probability levels, respectively; NS = Not significant at 5% probability level.
OC =organic content, OM= organic matter, TN= total nitrogen, TEA=total exchangeable acidity, AL= luminum, H= hydrogen,
Ca= calcium, Mg= magnesium, potassium, Na= sodium, TEB= total exchangeable base, CEC= cation exchangeable capacity, BS=base saturation, Avl. P = available phosphorus

CONCLUSION

This research was carried out in Ikeduru to assess soil properties of a toposequence. A transect survey technique was used to align soil profile pit along the toposequence. Three profile pits were dug, described and samples collected for repetitive laboratory analysis for selected physiochemical properties using ANOVA for a CRD experiment. LSD at 5% probability level was utilized to separate the toposequence significantly. A correlation investigation carried out was used to explain relationships among selected physiochemical properties of the studied soils. The result of the physiochemical properties of the toposequence varied with depth. The physico-chemical properties of the soil in the various topo-sequence with respect to their mean values were found to have a higher value, though lower slope than the upper as well as middle slopes. It was observed that erosion experienced in the study area includes sheet, rill and gully erosions, though rill erosion was observed to be more rampant within the area. It could be established that some of the mineral content of the soil was lost through leaching in the area. The soil of the area was found to have high acidic content caused by the continuous tiring and destruction of the top soils through erosion by sheet and later to gully erosion enhanced by human and animal actions. The climatic and environmental factors are contributory to the erosion hazards due to the undulating and irregular land form. Also, the rate at which land is made use of becomes a major factor that causes soil erosion, such includes, building of houses, road constructions, burning of bushes, stone quarrying are contributory factors that causes the erosion of soils in the research region. This study will go a long way to supporting researchers, farmers and agriculturist who will want to embark on massive agricultural production in different countries of the world that have similar land terrain and it can be expanded to accommodate other regions of the country and the world at large.

DECLARATION OF COMPETING INTEREST

We authors hereby affirm that there is no conflicting of interest whatsoever.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors hereby declare that the contributions given are correct.
Patricia Akunna Oriaku: Review and methodology,
Christopher Ikechi Obineche: Writing original draft and investigation,
Nkechi Udochukwu Ezechike: Validation of results,
Patience Chinasa Ezema: Statistical and data review.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1128061

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 308-324

Research Article

Assessment of Compressive Strength Variations of Concrete Poured in-Site of Residential Buildings in Isoko District, Delta State, Nigeria

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ABSTRACT

Concrete with appreciable compressive strength is required for building constructions, to minimize the occurrence of building failures. Determination of the compressive strength of in-situ concrete produced in Isoko region of Nigeria was carried in this study. Concrete used for the construction of foundation wall footings for twenty residential buildings were sampled in the study. The compressive strength of the in-situ concrete was determined in accordance with ASTM standards. Field survey depicted that most (60%) of the concrete quality production process fell below the approved standard of 17 MPa, for residential buildings. The findings of the study revealed that the compressive strength of the in-situ concrete varied between 8.1 MPa and 19.8 MPa. Furthermore, the result of the compressive strength test showed that most (70%) of the in-situ concrete failed to meet the NIS recommended standard. Also, it was observed from the findings that proportionally, the concrete produced by conventional building/construction engineers was of a higher compressive strength, when compared to the concrete produced solely by masons. Based on observations obtained result obtained from this study, it is recommended that the Government should constantly educate building sites managers, on the need to adhere strictly to standard recommendations, in order to improve the quality of in-situ concretes produced.

RESEARCH ARTICLE

Received: 08.06.2022
Accepted: 17.11.2022

Keywords:

- Compressive strength,
- In-situ concrete,
- Nigeria,
- Residential buildings,
- Structural failure

To cite: Uguru H, Akpokodje OI and Agbi GG (2022). Assessment of Compressive Strength Variations of Concrete Poured in-Site of Residential Buildings in Isoko District, Delta State, Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 308-324.* https://doi.org/10.46592/turkager.1128061

INTRODUCTION

Concrete is a cement-based composite material that is widely utilized in civil engineering construction work, due to its high compressive strength, it's good thermal and radiation resistance, and it's durability, amongst other related factors (Kumbhar and Murnal, 2012; Akpokodje *et al.*, 2020). Some parts of building structures that are largely utilize concrete include: foundation footings, floors, basement walls, columns, beams, slabs, etc. The quantity of fine and coarse aggregates, the volume and cement grade, the production process, the curing methods, the water-cement ratio and the admixtures added, amongst other factors, significantly affect the physic-mechanical properties of the concrete (Okumu *et al.*, 2016; Ribeiro *et al.*, 2016; Akpokodje *et al.*, 2021). Although concrete strength is dependent on the water volume present in the fresh concrete, excessive water affects the quality of concrete gel produced (C-S-H) and predisposes the concrete so produced to failures (mostly in the form of shrinkage and cracking). Marar and Eren (2011) stated that the workability of fresh concrete is dependent on the mix ratio and the water-cement ratio; a higher cement or water volume usually result in a higher workability of the fresh concrete.

Concrete compressive strength is one of the leading factors that determines the stability and durability of concrete structures. Careful planning and supervision are necessary to avert poor quality in-situ concrete, resulting mostly from human deficiencies; that is laborer related short comings and sharp practices. Visual evidences of poor quality concrete include: scaling, discoloration, cracking, etc., Scanlon (2013), which are caused by poor quality materials, overloading, poor production, poor quality control and inadequate designs for the expansion and contraction characteristics of the concrete (Richard, 2002). Strict adherence to recommendations made by Nigeria Industrial Standard (NIS) for the construction of structures is a presently a mirage in Nigeria. Apart from buildings owned by government and corporate organizations, a vast majority of buildings in Nigeria are constructed by artisans with inadequate design and construction certification, and largely using sub-standard materials during building construction (Oloyede *et al.*, 2010; Obukoeroro and Uguru, 2021). According to Adewole *et al.* (2014) craftsmen typically carried out building constructions without prior soil tests and other required professional steps, but rather, adopt assumptive methods, to the detriment of their clients.

Building failures are becoming frequent in Nigeria, and were particularly extensive in 2020 and 2021. Nigerian Institute of Structural Engineers (NISE) has attributed most of the building failures in Nigeria to poor design, low quality concrete, faulty construction, poor supervision, substandard materials, etc., (Oloyede *et al.*, 2010; Amadi *et al.*, 2012; Oyawa *et al.*, 2016; Uguru, 2016). Likewise, the Council for the Regulation of Engineering in Nigeria (COREN) has blamed structural failures in Nigeria on poor structural designs and substandard building materials. Chendo and Obi (2015) stated that imperfection in structural design is one of the major causes of building failures globally. Furthermore, Adebayo (2010) reported that some structures failed mainly due to inadequate soil tests, deviations from the original design (which add an extra loads to the footings), earthquakes, and poor supervision. To prevent failures (indiscriminate cracking) which can ultimately lead to poor serviceability or catastrophic conditions, control or expansion joints should be inserted into large concrete slabs or floors, at regular intervals (Scanlon, 2013).

Approximately 2000 people have died from building failures within the past two decades in Nigeria. According to Sikhakhane (2021), 115 cases of building failures were recorded in Lagos State alone, in southern Nigeria between 2005 and 2016. Major buildings in Nigeria that recorded large casualties include: the Synagogue Church building collapse in 2014 and Reigners Bible Church International building collapse in 2016 (Uguru, 2016; Mathebula and Smallwood, 2017). According to COREN, foundations, floors, beams and column failures, resulting from quackery, poor maintenance, etc., are some of the leading causes of building collapse in Nigeria (Uguru, 2016). To prevent structural failures, it is recommended that concrete used for residential structures should have a compressive strength of not less than 17 MPa; while concrete used for commercial structures, and structures exposed to harsh environmental conditions should not be less than 31 MPa (ACI 318, 2011).

Several researchers (Namyong *et al.*, 2004; Okazaki *et al.*, 2012; Ribeiro *et al.*, 2016) had studied the compressive strength of in-situ concrete used for various building constructions across the world. However, current literature search revealed little information on the compressive strength of concrete used for residential building construction in Delta State, Nigeria. Hence, the objective of this study was to measure the compressive strength of in-situ concretes used for the construction of residential building wall foundation footings within the Isoko region of Delta State, in Southern Nigeria, and to verify if they are in compliance with NIS and other related international approved standards.

MATERIALS and METHODS

Area of study

Isoko is one of the major tribes in Nigeria, with a human pollution of about 800.000 people, comprising of 8 major communities and several rural communities. Isoko inhabits two universities, a technical college, a theological school, numerous small and medium scale enterprises, several oil exploring companies, etc. Resulting from population and industrial expansion, lots of building constructions (including residential buildings) are taking place in the region (Agbi *et al.*, 2020; Uguru and Obukoeroro, 2020). As a result of this, Isoko region was chosen as study area for this research.

Borrow pit sharp sand (Figure 1) is majorly used for civil engineering and building construction works in the region, however, a few site managers employ river bed sharp sand for their construction work. Geographically, Isoko experiences two major seasons (wet and dry). The wet season occurs between March and September, with temperatures of 24±4°C while the dry season occurs between September and March, with a temperature range of 31±4°C. The study was carried between August 2021 and January 2022 - involving the two climatic seasons (wet and dry seasons).

Figure 1. Point of collection of borrow pit sharp sand.

Samples collection

Twenty (20) residential/commercial structures and construction sites (one shown in Figure 2) were visited for the purpose of this study. The sites were selected randomly, but were evenly distributed across the Isoko metropolises to present a fair representation of building population in the region. The sampling number adopted was fairly representative of the number of site managers (masons and engineers) actively available on building projects within the region. A mason here is considered to a site manager without formal tertiary engineering education, but responsible for the construction; while an engineer is the site manager with such formal education, and also responsible for the construction. Double counting was strictly avoided, as only one building site was selected per site manager captured in the study. For uniformity, only single and two storey reinforced concrete structures were captured for this study.

Figure 2. A typical building construction site.

Field observation

At each building site, thorough observations were made in order to obtain valid information, such as: type of cement used, mix ratio, water to cement ratio, concrete production methods, etc. Data collection during the fieldwork was through observations and organized interview questions.

Sieve analysis

The sieve analysis of the fine aggregate used for the concrete production was done in accordance with NIS-87 procedure. 500 g of dry sand (fine aggregate) was poured into a pre-arranged set of sieves, arranged in a descending order. The sieves were shaken vigorously for 15 minutes, and allowed to stand for another 10 minutes, so that the fine particles can settle. Then, each sieve was removed from the set, starting with the uppermost one, and weighed with a digital weighing balance (Figure 3). A particle size distribution curve was plotted as described by (Odeyemi *et al.*, 2015), and the coefficient of uniformity (Cu) was calculated using the expression given in Equation 1 (USCS, 2015).

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

Where:
C_u = uniformity coefficient (ASTM D2487),
D_{60} = 60% of finer grain size soil
D_{10} = 10% of finer grain size soil (USCS, 2015).

USCS stated that a sand is tagged Poorly Graded (P) when the C_u is less than six, and fines are less than 5 percent; and a sand is tagged Well Graded (W) when the C_u is greater than six and the fines are less than 5 percent.

Figure 3. Weight of the sand retained in the sieve.

Concrete cube production and curing

At each building site, four (4) concrete cubes were made, in accordance with ASTM International standard, from the fresh concrete collected from the various construction sites (Figure 4). During concrete cube production; freshly mixed concrete was poured into standard moulds in three equal layers, rammed thirty-five times per layer, and then flattened on the exposed surface with a hand trowel in order to produce a fairly flat surface finish.

Figure 4. Taking of fresh concrete for laboratory analysis.

The produced concrete cubes were shielded from exposure with black polyethylene sheets and left under shaded environments for 24 h, before they were all transported to the laboratory. In the laboratory, the concrete cubes were removed from the moulds, after 24 h, and cured through the total water immersion method for 28 days.

Slump test

At each sampling site, the slump test was used to determined the concrete's determine the consistency. The general procedures for concrete slump testing were performed in accordance with ASTM International standards (Figure 5).

Figure 5. Taking of the slump measurement.

Compressive strength test

The crushing force of concrete was measured in accordance with procedures set by ASTM C109/C109M (2020), using a concrete crushing machine (Figure 6). Four concrete cubes were tested for each construction site, and the average recorded.

Figure 6. A concrete cube undergoing compression testing.

The compressive force was calculated by the formula given in Equation 2 (Akpokodje *et al.*, 2021a).

$$Compressive\ strength = \frac{F}{A} \quad (2)$$

Where:
F = force required to crush the concrete cube (N)
A = effective area of the concrete cube (mm^2)

Statistical analysis

Raw data obtained from this research were statistically presented and analyzed using the pie chart, the bar chart and Analysis of Variance (ANOVA), through the aid of the MS-Word excel package.

RESULTS AND DISCUSSION

Field information

Table 1 shows the result of the analysis of fieldwork. As can be seen in Table 1, only 8 of the sites managers took cognisance of the water-cement (w/c) ratio, which ranged between 0.45 and 0.60. The result revealed that most (12) of the site managers continued to add water to the concrete until it becomes workable. This had led to addition of excess water to the concrete in most cases. From the field survey, out of the 20 sites managers, only 4 (20%) of them were qualified civil or structural engineers, while the remaining 16 (80%) sites managers were Masons. This is in conformity with related reports (Oloyede *et al.*, 2010; Adewole *et al.*, 2015), which stated that about 70% of buildings in Nigeria are constructed by unqualified professionals (e.g. craftsmen).

Generally, batching by volume method was adopted by all the sites managers, and problems of under batching or over batching was conspicuously observed on some building sites; mostly, on sites managed by masons. This can result in deviations or serious decline in the mechanical properties of concrete so produced, hence, making the building susceptible to economic and structural failures.

With respect to the concrete mix ratio, observations made revealed that the concrete mix ratio varied from a lean 1:3:6 mix to a much leaner 1:5:10 mix for the concrete works; many (40%) of the site managers' tended to use mix-ratios that are leaner than appropriate conventional specified grades, and which produced poor and relatively unacceptable concretes. A 1:5:10 mix ratio, closely relating to grade M 5 at curing day 28, had predominantly and previously been observed (Mishra, 2021). It was also observed from the result (Table 1), that all the site managers used a uniform coarse aggregate size (19 mm), for the in-situ concrete production. Moreover, the result revealed that majority (60%) of the managers used manual mixing methods, which they considered to be less expensive; but which were often to the detriment of the property owner in terms of mechanical quality. It had been experimentally verified (Aguwa, 2006) that concrete produced through manual mixing processes, tend to have poorer compressive strengths, when compared to concrete produced through mechanical machine mixing processes. Further analysis of the result revealed that the certified engineers used mechanical machine production processes, which can be attributed to the awareness obtained through their formal education.

Table 1. Concrete proportions adopted.

Building site	Mix ratio	Concrete Grade	w/c (%)	Site supervisor	Mix method	Coarse aggregates size	Batching method
1	1:5:10	M 5	0.45	Mason	Mechanical	19 mm	Volumetric
2	1:3:6	M 10	0.55	Engineer	Mechanical	19 mm	Volumetric
3	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
4	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
5	1:4:8	M 7.5	0.50	Engineer	Mechanical	19 mm	Volumetric
6	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
7	1:3:6	M 10	0.5	Engineer	Mechanical	19 mm	Volumetric
8	1:3:6	M 10	ND	Mason	Manual	19 mm	Volumetric
9	1:5:10	M 5	0.55	Mason	Manual	19 mm	Volumetric
10	1:5:10	M 5	0.60	Mason	Manual	19 mm	Volumetric
11	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
12	1:5:10	M 5	ND	Mason	Mechanical	19 mm	Volumetric
13	1:3:6	M 10	ND	Mason	Mechanical	19 mm	Volumetric
14	1:3:6	M 10	0.50	Mason	Mechanical	19 mm	Volumetric
15	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
16	1:4:8	M 7.5	ND	Mason	Manual	19 mm	Volumetric
17	1:4:8	M 7.5	0.50	Engineer	Mechanical	19 mm	Volumetric
18	1:5:10	M 5	ND	Mason	Manual	19 mm	Volumetric
19	1:5:10	M 5	ND	Mason	Mechanical	19 mm	Volumetric
20	1:3:6	M 10	ND	Mason	Manual	19 mm	Volumetric

ND = not determined

Fine aggregates quality

The result of the sieve analysis of fine aggregates used at the building construction sites is presented in Figure 7. The result showed a great variety in the quality of fine aggregates used for building construction in the region. It could be observed from Figure 1, that out of the 20 building sites, only 39% of the managers used well graded fine aggregates for their concrete production, while the remaining managers (61%) used poorly-graded fine aggregates for their concrete production. This can be attributed to the general high cost of the well-graded fine aggregates. Within the Isoko region, the price of 20 tons of well-graded fine aggregates is twice the price of 20 tons of poorly graded fine aggregates; thus many site managers tend to use the lower cost fine aggregates, usually to the detriment of the concrete's quality. According to USCS and NIS, only well graded fine aggregates are recommended for concrete production, since they tend to produce high quality concrete; thereby, minimizing chances of structural failures (USCS, 2015).

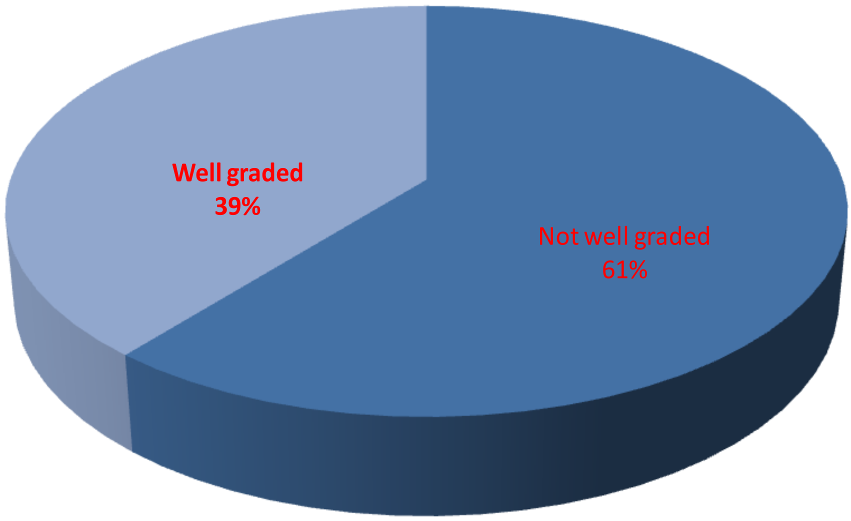

Figure 7. The quality of the fine aggregates.

The concrete slump

The result of the concrete slump from all the building sites is presented in Figure 8. Figure 8 revealed that the concrete slump varied between 39 mm and 71 mm. As shown by the result, concretes produced with unspecified water volumes had higher slump values when compared to concretes produced with specified water volumes. As presented in the chart (Figure 2), building sites 3, 6, 18 and 19, had the highest slumps of 61 mm, 65 mm, 71 mm and 65 mm, respectively; this could influence the quality of hardened concrete produced. Although a higher slump value implies better workability of the concrete, it is however a serious drawback factor to the concrete's mechanical properties (ACI 332.1R-06, 2006), especially if it result from added water. According to Scanlon (2013), higher slump values (due to additional water) tends to produce concrete with weaker compressive strengths, because the cement paste becomes leaner and weaker, and shrinkage occurs within the concrete. Also, concretes with higher slump values, tend to attain poorer quality consolidation during compaction/vibration due to aggregate particle segregation, resulting in the production of a weaker quality of concrete (ACI 303R, 2012).

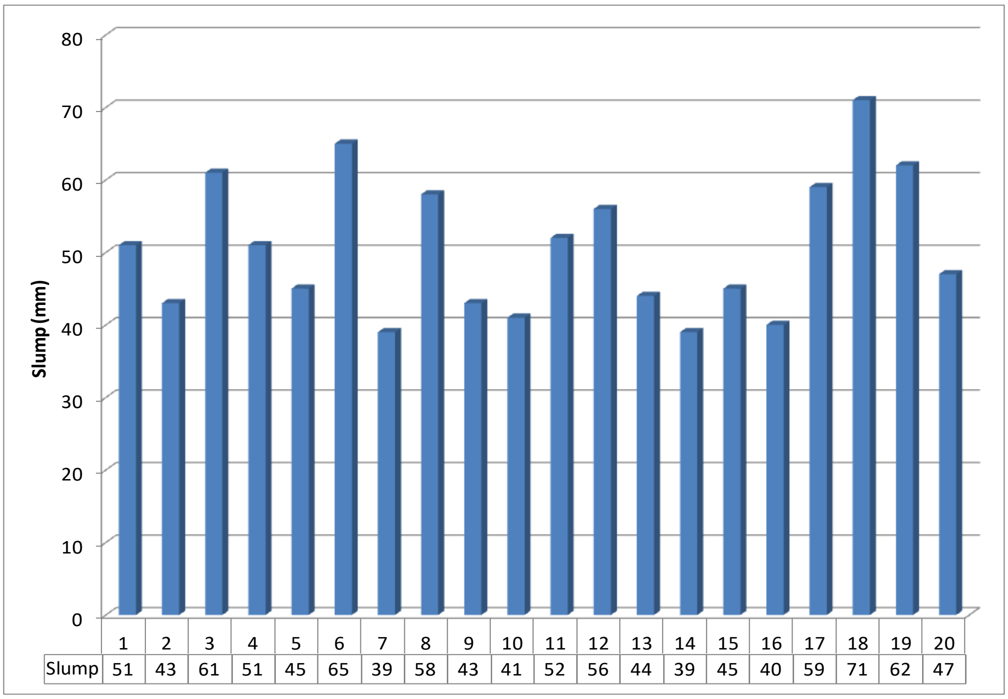

Figure 8. In-situ concrete slump.

Compressive strength

The ANOVA result of the effect of sampling location on the concrete's compressive strength is presented in Table 2. It was observed in Table 2 that there was significant difference between the concrete samples.

Table 2. ANOVA of the effect of building site on the concrete compressive strength.

Source of Variation	SS	DF	MS	F	P-value	F critic
Between Groups	624.43	19	32.86	117.86	3.75E-29	1.85
Within Groups	11.15	40	0.28			
Total	635.58	59				

The mean compressive strength of the in-situ concrete obtained in this study is presented in Table 3. The information in Table 3 portrayed that the compressive strength of in-situ concretes used in the area ranged from 8.1 MPa to 19.8 MPa. As depicted by the result. Only 6 buildings (2, 7, 13, 14, 16 and 20) attained the recommended concrete compressive strength (17 MPa and above) for residential buildings; the concretes for the remaining 14 buildings, failed to meet the allowable compressive strength threshold recommended for residential buildings. It was noticed that in building 19, despite the comparatively leaner mix ratio, a higher concrete compressive strength was obtained. This could be caused by incorrect batching during the concrete production, as a higher cement volume may have been used in the concrete production, thereby producing concrete with a higher compressive strength. Bhattarai and Mishra (2017) reported that improper batching and mixing of concrete constituents, generally affect the concrete quality produced.

It was observed in the result (Table 3) that the buildings that satisfactorily met the compressive strength requirement, were those that the managers utilized lower water-cement ratios and fairly conventional concrete mix ratios. This confirmed a previous report by Ribeiro *et al.* (2016) which stated that water-cement ratios considerably affect the compressive strength of in-situ concretes. The poor quality concrete produced in building 8, despite its better mix ratio, could be attributed to the volume of water and the production method used during the concrete production. Water quality and quantity, the mixing method and the curing method, are some influential factors that affect the compressive strength of in-situ concrete (Abdullahi, 2012; Ribeiro *et al.*, 2016); therefore, site managers should adhered strictly to the required volume of water used for concrete production.

Furthermore, the closely related concrete compressive strengths (13.5 MPa, 10.5 MPa and 14.5 MPa) observed in building sites 8, and 4 and 15 respectively, despite the different concrete mix ratios adopted, could be attributed to variations in the quality of the component materials used for the concrete productions. Okumu *et al.* (2017) in their research observed that, poor quality materials (sand, gravel, etc.) largely affected the compressive strength of the in-situ concrete produced. Result obtained in this study are similar to those obtained by Sisay (2017) who observed great discrepancies in the concrete used for residential building constructions in Ethiopia. Sisay (2017) reported that the in-situ concrete produced in Addis Ababa varied between 15.39 MPa and 33.05 MPa.

Table 3. Compressive strength data of the in-situ concrete used for the building construction.

Building	Compressive strength (MPa)*
1	9.5±1.5
2	18.3±1.9
3	13.4±1.3
4	13.5±2.4
5	15.8±1.7
6	8.1±1.2
7	19.8±2.1
8	10.5±1.7
9	14.3±1.6
10	12.6±1.9
11	15.2±2.1
12	14.6±1.1
13	18.1±1.8
14	17.5±2.2
15	14.5±2.1
16	17.3±2.2
17	14.9±1.4
18	9.2±1.3
19	16.4±1.9
20	17.6 ±2.1

* n= 4; ± standard deviation

Furthermore, the poor concrete quality recorded in some of the building sites, despite the fair mix ratios and good production methods, could be as a result of environmental conditions. During hot weather (as experienced in the dry season in Nigeria), the rate of water evaporation from fresh concrete tends to be higher, thus making the cement dry out and set speedily; thereby, producing concretes with lower compressive strengths, if such concretes are not cured appropriately. In a research carried out by Salem and Pandey (2017), the authors observed that the concrete compressive strength declined from 22.3 MPa to 17.25 MPa, as the water to cement ratio was increased. Similarly, Adeyemi *et al.* (2019) reported that compressive strength tests showed that concrete cubes gained strength with increase in curing age but strength decreased with an increase in the water to cement ratio. As reported by Adeyemi *et al.* (2019), the compressive strength of concrete declined from 25 MPa to 19 MPa, as the water-cement ratio increased from 0.4 to 0.6.

From the study's result, it is advisable for site managers to employ the use of retarders during hot weather concreting, in order to delay the setting of the concrete and reduce evaporation, thereby enhancing the hydration process of the cement. Scanlon (2013) reported that high temperatures facilitate concrete's setting time. Finally, the volume of water utilized for concrete production should be closely monitored, as the findings from this study had corroborated the fact that water volume greatly influences the compressive strength of concrete.

Relationship between the concrete slump and the compressive strength

Figure 9 and Table 4 show the relationship between in the in-situ concrete compressive strength and the slump. As presented in Table 3, significant ($p \leq 0.05$) relationship existed between the concrete slump and its compressive strength. This is an indication that the slump had significant ($p \leq 0.05$) influence on the compressive strength of the concrete produced in the Isoko district. The chat (Figure 9) depicted that the concrete compressive strength was inversely proportional to the slump result. It was noted that the concrete strength declined non-linearly, as the concrete slump increases. This is a confirmation of Scanlon (2013) report that concrete with higher slump values tends to produce poor compressive strength, unless special additives are added to the concrete.

Table 4. The ANOVA result of the effect of slump on concrete compressive strength.

Source of Variation	TSS	df	MSS	F	P-value	F crit
Between Groups	12992.42	1	12992.42	255.74	1.83E-18*	4.09
Within Groups	1930.55	38	50.81			
Total	14922.98	39				

* = Significant at $p \leq 0.05$

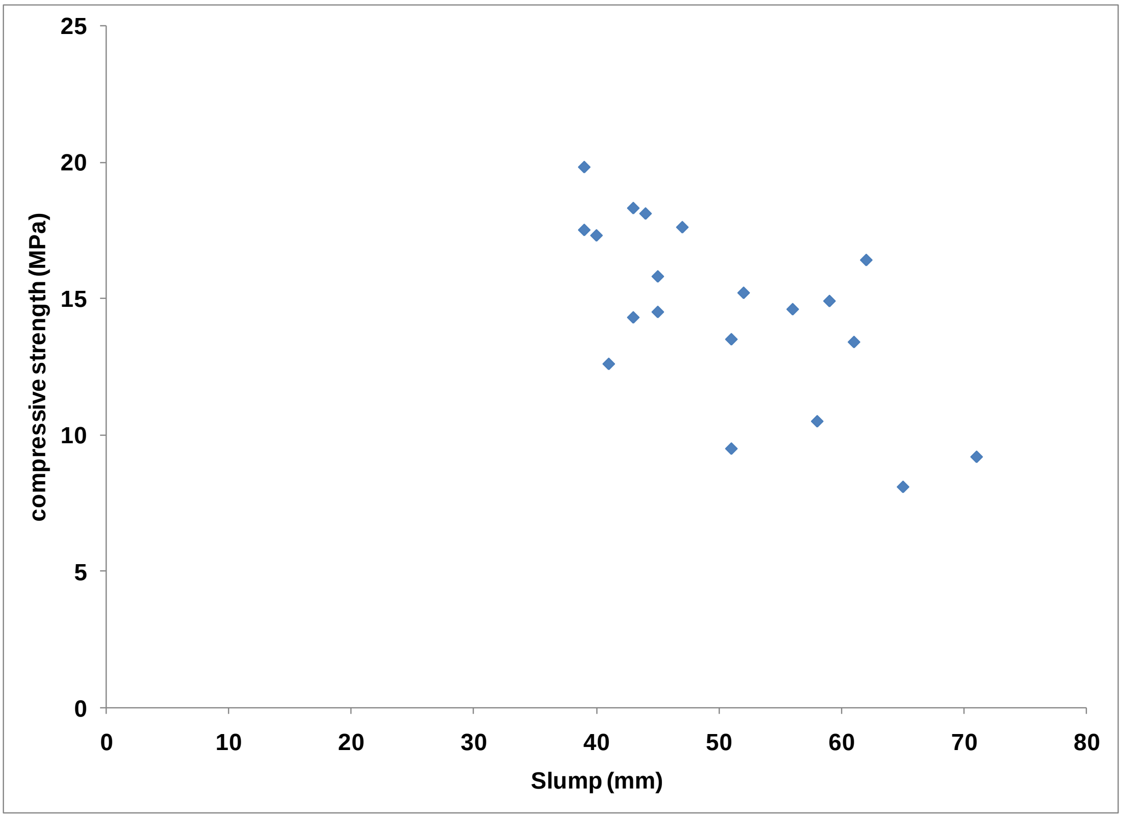

Figure 9. Relationship between concrete compressive strength and its slump.

CONCLUSION

Concrete plays a key function in building structures and residential building construction, but its quality is barely adequately monitored in Nigeria. This study is an appraisal of the concrete used for the construction of foundation wall footings for residential buildings in Isoko region of Nigeria. It identifies the common concrete production hitches and proffers recommendations. Field observations revealed that most (60%) of the in-situ concrete produced do not adhere to the NIS and ASTM recommendations for concrete production. The findings depicted that only 30% of the building sites sampled met the recommended compressive strength (17 MPa) for concrete to be used for residential buildings construction (this is inspite of the general inadequate mix ratios presented); while the concrete used for the remaining 70% of buildings sampled, fell below the 17 MPa approved threshold. Based on the findings of this study, it was ascertained that the conduct and quality of site managers greatly affects the quality of concrete produced; concretes produced by engineers were of a fairly higher compressive strength compared to those produced by masons. It can be concluded from this study that a lack of appropriately qualified professional involvement in the concrete production process contributed considerably to the general poor quality of concrete produced for the foundations of the residential buildings in the region, which has generally reflected as cracking on buildings walls in the region. Based on the findings of this study, the following recommendations can be made:

i. Seminars and regular site visits should be provided by the Government in collaboration with COREN and NSE (Nigerian Society of Engineers) to educate masons and engineers, as part of post qualification and continued education training on construction practice, and on the specific issue of adequate mix ratios and how to effect and improve the quality of in-situ concretes.

ii. Buildings supervisors should ensure the use of standard materials and methods for their building construction. This should be backed by adequate and effective monitoring by appropriate governmental agencies.

iii. Masons should never be sole managers of building sites as they are technically ill equipped for such arrangements; hence, qualified or certified engineer/personnel should superintend.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Hilary Uguru: Designed the research
Ovie Isaac Akpokodje: Edited the manuscript.
Goodnews Goodman Agbi: Write the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1125258

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 325-337

Research Article
(Araştırma Makalesi)

Determination of Useful and Total Phosphorus Content of Develi Plain Soils

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ABSTRACT

Phosphorus, one of the macronutrients, is of great importance for soil fertility in terms of the sustainability of agricultural production. When the phosphorus (P) amounts in the soils of our country were investigated, it was determined that the total phosphorus (TP) amounts were at a good level, but the available phosphorus (YP) levels were insufficient. In this study, pH, EC, TP and YP contents of soil samples taken from 0-30, 30-60 and 60-90 cm depths at the coordinates determined in the Develi Plain soil were determined and examined. The lowest pH and EC values of the soils of the study area at 0-30, 30-60, 60-90 cm were 6.75, 6.80, 7.50 and 0.25 dS m^{-1}, 0.25 dS m^{-1}, 0.31 dS m^{-1}, respectively, and the highest the value was measured as 9.88 and 110.1 dS m^{-1}. In addition, the lowest TP content was 52.6 mg kg^{-1}, 80.6 mg kg^{-1}, 85.3 mg kg^{-1}, the highest TP content was 1582 mg kg^{-1}, 1004.5 mg kg^{-1}, 950 mg kg^{-1}, respectively, The lowest YP content at 0-30, 30-60, 60-90 cm was 5.1 mg kg^{-1}, 0.1 mg kg^{-1}, 1.15 mg kg^{-1}, the highest YP content was 77.1 mg kg^{-1}, 78.7 mg kg^{-1} respectively. It was determined as 1.52.3 mg kg^{-1}. As a result of the study, the TP of the soil samples was found to be higher than the YP value in general.

RESEARCH ARTICLE

Received: 03.06.2022
Accepted: 17.11.2022

Keywords:

- Available phosphorus,
- Total phosphorus,
- Sustainable soil fertility,
- Develi Plain

To cite: Yılmaz Y, Kılıç FY and Sönmez O (2022). Determination of Useful and Total Phosphorus Content of Develi Plain Soils. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 325-337.* https://doi.org/10.46592/turkager.1125258

Develi Ovası Topraklarının Yarayışlı ve Toplam Fosfor İçeriklerinin Belirlenmesi

ÖZET

Tarımsal üretimin sürdürülebilirliği açısından makro besin elementlerinden biri olan fosfor toprak verimliliği için büyük önem taşımaktadır. Ülkemiz topraklarında fosfor (P) miktarları araştırıldığında toplam fosfor (TP) miktarlarının iyi düzeyde olduğu ancak yarayışlı fosfor (YP) düzeylerinin yetersiz olduğu saptanmıştır. Bu çalışmada Develi Ovası topraklarında belirlenen koordinatlarda 0-30,30-60 ve 60-90 cm derinlikten alınan toprak örneklerinin, pH, EC, TP ve YP içerikleri belirlenmiş ve incelenmiştir. Çalışma alanı topraklarının 0-30, 30-60, 60-90 cm'deki en düşük pH ve EC değerleri sırasıyla 6.75, 6.80, 7.50 ve 0.25 dS m^{-1}, 0.25 dS m^{-1}, 0.31 dS m^{-1}, en yüksek değer 9.88 ve 110.1 dS m^{-1} olarak ölçülmüştür. Ayrıca en düşük TP içeriği sırasıyla 52.6 mg kg^{-1}, 80,6 mg kg^{-1}, 85.3 mg kg^{-1}, en yüksek TP içeriği sırasıyla 1582 mg kg^{-1}, 1004.5 mg kg^{-1}, 950 mg kg^{-1} olarak, 0-30, 30-60, 60-90 cm'deki en düşük YP içeriği sırasıyla 5.1 mg kg^{-1}, 0.1 mg kg^{-1}, 1.15 mg kg^{-1}, en yüksek YP içeriği sırasıyla 77.1 mg kg^{-1}, 78.7 mg kg^{-1}, 52.3 mg kg^{-1} olarak saptanmıştır. Çalışma sonucunda toprak örneklerinin TP, YP değerine göre genel olarak yüksek bulunmuştur.

ARAŞTIRMA MAKALESİ

Alınış tarihi: 03.06.2022
Kabul tarihi: 17.11.2022

Anahtar Kelimeler:

- Yarayışlı fosfor,
- Toplam fosfor,
- Sürdürülebilir toprak verimliliği,
- Develi Ovası

Alıntı için: Yılmaz Y, Kılıç FY ve Sönmez O (2022). Develi Ovası Topraklarının Yarayışlı ve Toplam Fosfor İçeriklerinin Belirlenmesi. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 325-337.* https://doi.org/10.46592/turkager.1125258

GİRİŞ

Toprağın sürdürülebilir şekilde kullanımının önemi son yıllarda giderek artmıştır. Başta bitkiler olmak üzere birçok canlının yaşam ve besin kaynağı topraktır. Nüfus artışı ile orantılı olarak gıda talebi, gıda tüketimini karşılamak amacıyla bitkisel üretim değerlenmiştir (Mikhailenko ve ark., 2020; Sönmez ve Kılıç, 2021). Fosfor (P) toprak içerisinde organik ve inorganik bileşikler formunda bulunan ve canlılar için hayati önem taşıyan makro besin elementlerinden biridir. Bitkiler, toprak çözeltisinden P'yi genellikle negatif yüklü birincil ve ikincil ortofosfat iyonları formunda bünyelerine almaktadır (Condron ve Newman, 2011). Toprakların çoğu ciddi miktarda toplam fosfor (TP) stoğu içermekte ve toprakların toplam fosfor içerikleri çoğunlukla 500-800 mg kg^{-1} arasında değişim göstermektedir (Sönmez ve ark., 2016a). Buna rağmen, toplam inorganik fosfor (Pi)'un ve organik fosfor (Po)'un %1'den daha az kısmı bitkiler için yarayışlı durumdadır (Mengel ve ark., 2001; Bünemann, 2015; Sönmez ve Pierzynski, 2017). Bitkiler için fosforun çözünürlüğünün ve yararlanılabilirliğinin düşük olması, pH'ı yüksek topraklarda kalsiyum fosfatlar veya asidik topraklarda demir ve alüminyum oksitlerce bitkilerin yararlanamayacağı formlarda adsorbe olması ve çökelmesinden kaynaklanmaktadır (Alam ve Ladha, 2004; Sönmez ve Pierzynski, 2015). Tarım topraklarının fosfor düzeyleri hakkında birçok araştırma yapılmıştır. Mahdi ve ark. (2019) yaptıkları çalışmada Atabey Ovasından 0-20 cm'den alınan toprak örnekleri bitki örtüsü ve yeterli düzeyde gübreleme uygulamaları sonucunda, organik madde ve yarayışlı fosfor fraksiyonlarının artış eğiliminde olduğu saptanmıştır. Karaman ve ark. (2001), Kazova Ovasından alınan toprak örneklerinde uzaklık dikkate alındığında ihtiyaç duyulan fosfor ihtiyacının belirli kısımlarda yüksek belirli kısımlarda düşük olduğunu saptamıştır. İrik (2013), Develi Ovasında yaptığı çalışmada ova topraklarının 0-30 cm derinliğinde pH değerinin 6.9-9.9 arasında, 30-60 cm toprak derinliğinin pH'ı 5.4-9.9 arasında ve 60-90 cm toprak derinliğinin ise pH'ının 7-9.8 değerleri arasında değiştiğini saptamıştır ve toprak reaksiyonunun 7.5-8.2 arasında olan topraklarda kalsiyum bikarbonatların yoğun ve trikalsiyum fosfat halinde güç çözünür bileşikler olarak çökeldiğini bildirmişlerdir.

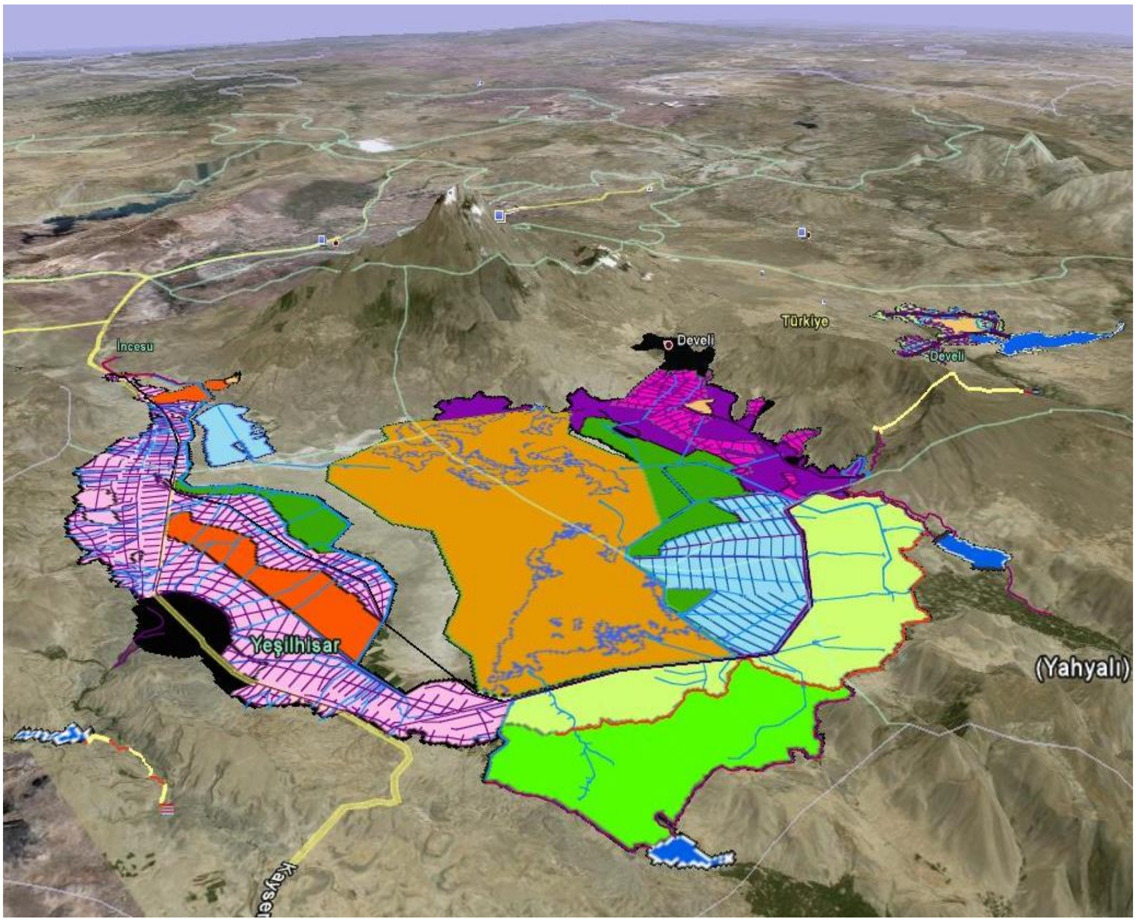
Tarım topraklarında besin kaynaklarının iyi yönetilmesi açısından fosfor içerikli gübrelerin uygulamasında, TP'nin yeterli veya yüksek seviyedeyken, YP'nin düşük seviyede olduğuna dikkat edilmelidir. Böyle durumlarda fosfor ilavesinin yapılması, bitkinin ihtiyaç duyduğu miktardan daha fazla miktarda fosfor sağlamaktadır. Tarım topraklarında fazla miktarda fosfor kullanımı maddi açıdan olumsuz sonuçlara neden olmakta, toprak, su kaynaklarımızın kirlenmesine yol açmaktadır.

Tarım topraklarının sürdürülebilirliği ve mahsul verimi için yenilenemez bir kaynak olan fosforun ihtiyaç talebini karşılayabilmesi, bunun içinde topraklarımızdaki TP ve YP durumlarının bilinmesi ve buna göre bilinçli bir fosforlu gübreleme planının oluşturulması gerekmektedir (Sönmez ve ark., 2016b). Develi Ovası'nda yürütülen bu çalışmada toplam fosfor (TP) ve yarayışlı fosfor (YP) durumlarının araştırılması amaçlanmıştır.

MATERYAL ve YÖNTEM

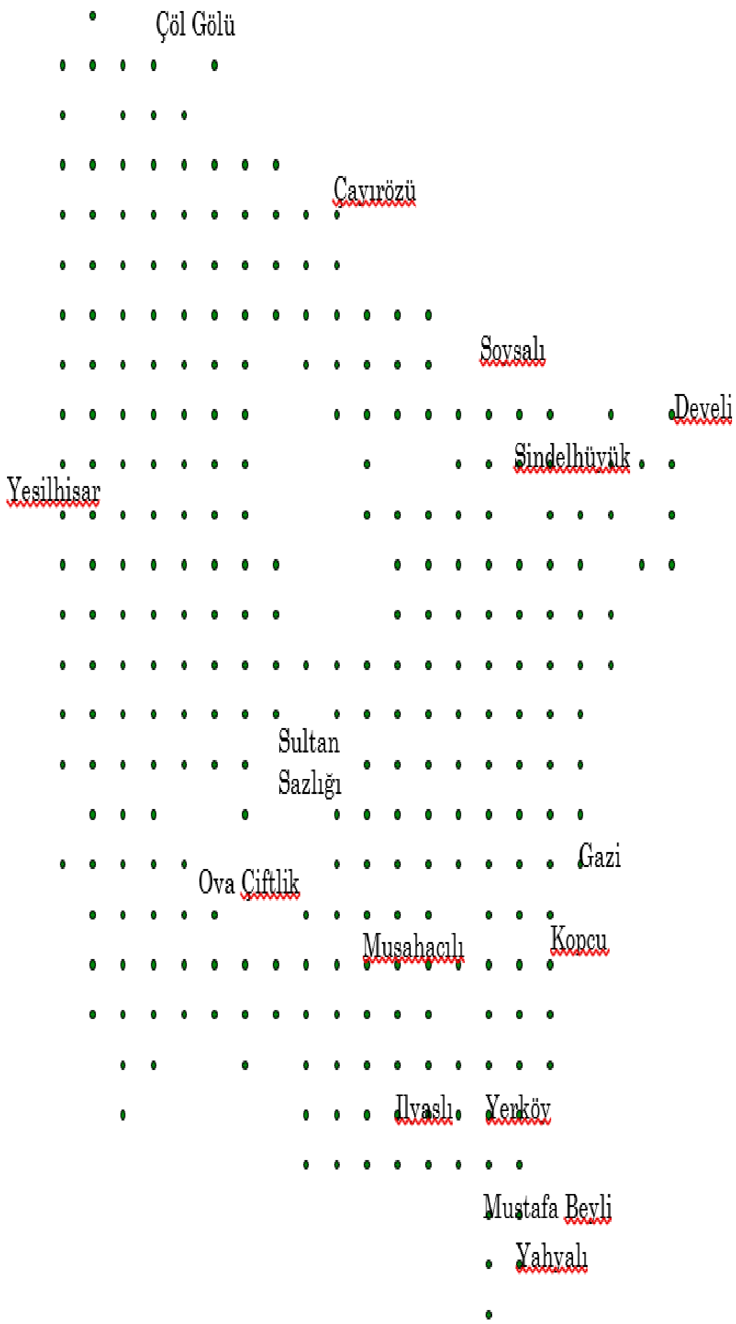
Develi Ovasının yüzölçümü 2072 km² olup, deniz seviyesinden yüksekliği 1070 m ile 1150 m arasında değişmektedir. Tarımsal açıdan işlenen alan Develi ilçesinde 669.514 da'dır. İl merkezi ve ilçenin topraklarının geneli değerlendirildiğinde alkali, tuzlu ve bozuk drenajlıdır. Develi Ovası'nın bazı bölgelerinde yer alan hidromorfik topraklar, organik madde düzeyi yüksek, koyu renkli alüvyal topraklar niteliğindedir. Kayseri ve Develi Ovasının bazı bölgelerinde yer alan kolüvyal topraklar ise zayıf yapılı ve drenajı durumu iyi olan topraklardır (Anonim, 2019). Karasal iklimin egemen olduğu Develi Ovasında aylık toplam yağış 3.56-50.78 mm civarında, ortalama sıcaklık değerleri, -0.5 -18.1°C civarında, ortalama nispi nemi (%) 47.2-71.3 değerleri arasında değişmektedir (Anonim, 2014). Develi Ovası İç Anadolu'nun Orta Kızılırmak bölümü 38-27° kuzey enleminde, 33-17° doğu boylamında yer almaktadır. Erciyes Dağının yaklaşık 6 km uzaklığında konumdadır. Develi Ovası ciddi öneme sahip sulak alanlardan birisi olan Sultan Sazlığı Kuş Cennetini barındırmaktadır.

Çalışma 2019 yılında Develi Ovasından 1500 m x 1500 m uzaklık belirli noktalardan, 0-30, 30-60, 60-90 cm derinliklerinden alınan toprak numuneleri ile gerçekleştirilmiştir (Şekil 1). İrik (2013), yaptığı çalışmada toprak örneklerinin alındığı noktalardan tekrar örnek alınarak kullanılmıştır (Şekil 2) (Şekil 3).



Şekil 1. Çalışma alanı.
Figure 1. *Study area.*

Şekil 2. Çalışma alanında bozulmuş toprak örneklerin alındığı noktalar (İrik,2013).
Figure 2. *The points where soil samples were taken in the study area (İrik, 2013).*



Şekil 3. Çalışma alanından toprak örneklerinin alındığı bazı bölgeler ve örnekleme noktaları (İrik, 2013).

Figure 3. *Some regions and sampling points where soil samples were taken from the study area (İrik, 2013).*

Yapılan çalışmada, toprak örneklerinin alındığı noktalar, Develi Ovası'nın sayısallaştırılmış 1/25000 ölçekli standart topoğrafik haritaları kullanılarak belirlenmiştir. Bu haritalar, ArcGIS 9.3 ortamına aktarılarak 1500 m × 1500 m düzenli kare ızgara sistemine aktarılmıştır. Tarımsal üretim yapılan alanlar, mera alanları ve Sultan Sazlığı Milli Parkı ve Ramsar alanı civarında belirlenen kare kesim noktaları, örnekleme noktaları olarak kabul edilmiştir. Örnek alınan noktaların coğrafi koordinatları ArcGIS yazılımı kullanılarak belirlenmiş bu koordinatlar GPS ortamına aktarılmıştır. Rastgele örnekleme metodu ile 0-30, 30-60 ve 60-90 cm olmak üzere 3 farklı derinlikten, belirlenen 288 noktadan toprak burgusu kullanılarak örnekler alınmıştır. Toprak örnekleri laboratuvarda hava kuru toprak haline gelinceye kadar kurumaya bırakılmış ve daha sonra 2 mm'lik elekten geçirilerek analizler için ön hazırlığı yapılmıştır. Örnekler daha sonra analizlerde kullanılmak amacıyla etiketlenerek polietilen poşetlerde muhafaza edilmiştir. Alınan örneklerin YP miktarlarının belirlenmesi için (Olsen ve ark., 1954) metodu kullanılmıştır. Metoda göre toprakta YP miktarı, 2 g toprak üzerinden 1 20^{-1} oranında toprak miktarının ekstraksiyon çözeltisine oranı sağlanmıştır. pH'sı 8.5 ayarlanan 0.5 M $NaHCO_3$ ilave edilerek 30 dk boyunca 160 rpm'de çalkalayıcıda çalkalanmıştır. Toprak örnekleri filtre kâğıdı ile süzülerek ölçü balonlarına aktarılmıştır. Alınan süzük mavi renk yöntemiyle 882 dalga boyunda Biotek marka spektrometrede belirlenmiştir. Hesaplanan değerlerin yorumlanması için YP'nin topraktaki seviyelerinin belirtildiği TOVEP (1991) sınır değerleri kullanılmıştır (Çizelge 1).

Çizelge 1. Topraktaki yarayışlı fosfor sınır değerleri (TOVEP, 1991).
Table 1. *Limit values of available phosphorus in soil (TOVEP, 1991).*

Yarayışlı fosfor (mg kg $^{-1}$)	Sınıflandırma
< 2.5	Çok düşük
2.5-8	Düşük
8-25	Yeterli
25-80	Yüksek
>80	Çok yüksek

Topraklarda TP analizi, yoğunluğu 1.54 g ml^{-1} ve yüzdesi %60 olan perklorik asit ($HCLO_4$) ile yaş yakılan toprak örneğinde çözünemez formda bulunan fosforun çözünebilir duruma dönüştürüp, mavi renk yöntemi ile 882 nm dalga boyunda spektrofometrede belirlenmiştir. Hesaplanan değerlerin yorumlanması için TP'nin topraktaki seviyelerinin belirtildiği Tripathi ve ark. (1970) sınır değerleri kullanılmıştır (Çizelge 2).

Çizelge 2. Topraktaki toplam fosfor sınır değerleri (Tripathi ve ark., 1970).
Table 2. *Limit values for total phosphorus in soil (Tripathi et al., 1970).*

Toplam Fosfor (mg kg $^{-1}$)	Sınıflandırma
300-500	Düşük
600-1000	Orta
>1000	Yüksek

Toprak reaksiyonu (pH) ve elektriksel iletkenlik (EC) için, 1:2.5 yöntemi uygulanarak 10 g toprak üzerine 25 ml su ilave edilip karıştırılmıştır. Elde edilen çözeltinin pH ve EC değerleri, pH metre ve kondüktivimetre ile ölçülmüştür. Doğan (1991) toprak reaksiyonu sınır değerleri ve Yüzbaşıoğlu ve Dağlıoğlu (2011) elektriksel iletkenliğin tuzluluğa etkisini belirleme değerlerinden faydalanılarak saptanan sonuçlar yorumlanmıştır (Çizelge 3) (Çizelge 4).

Çizelge 3. Toprak reaksiyonunu sınır değerleri (TOVEP, 1991).
Table 3. *Limit values for soil reaction (TOVEP, 1991).*

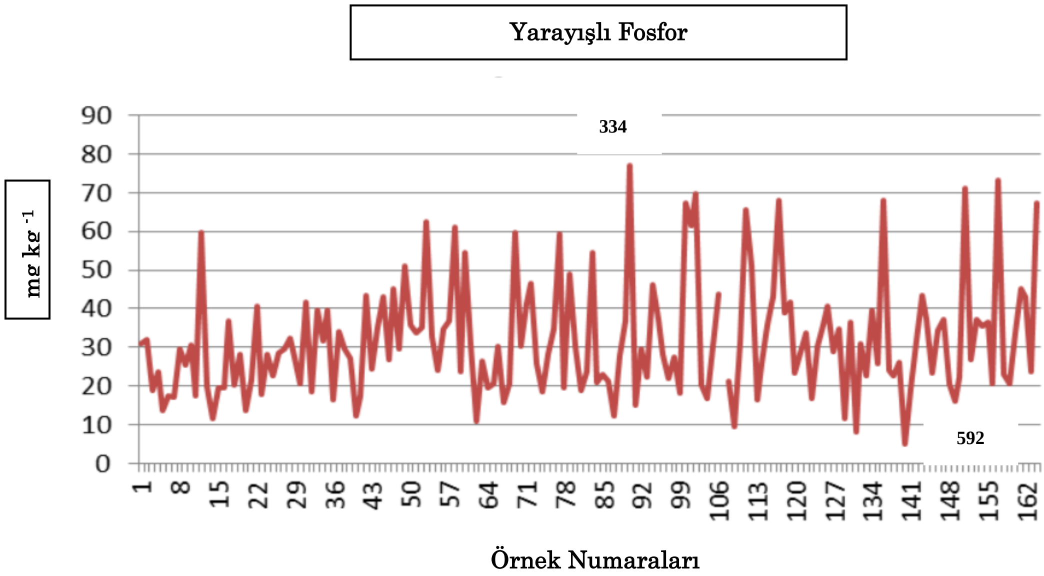
pH	Değerlendirme
< 4.5	Kuvvetli Asit
4.5- 5.5	Orta Asit
5.5- 6.5	Hafif Asit
6.5- 7.5	Nötr
7.5- 8.5	Hafif Alkali
> 8.5	Alkali

Çizelge 4. Elektriksel iletkenliğin tuzluluğa etkisini belirleme değerleri (Yüzbaşıoğlu ve Dağlıoğlu, 2011).
Table 4. *Values for determining the effect of electrical conductivity on salinity (Yüzbaşıoğlu and Dağlıoğlu, 2011).*

EC (mmhos cm^{-1})	Tuzluluğa olan etkisi
0-2	Tuz etkisi yok
2-4	Bazı duyarlı bitkilerde verim düşer
4-8	Ekseri bitkiler zarar görür
8-15	Sadece dayanıklı bitkiler yetişir
> 15	Sadece ot ve tuza duyarsız bitkiler yetişir

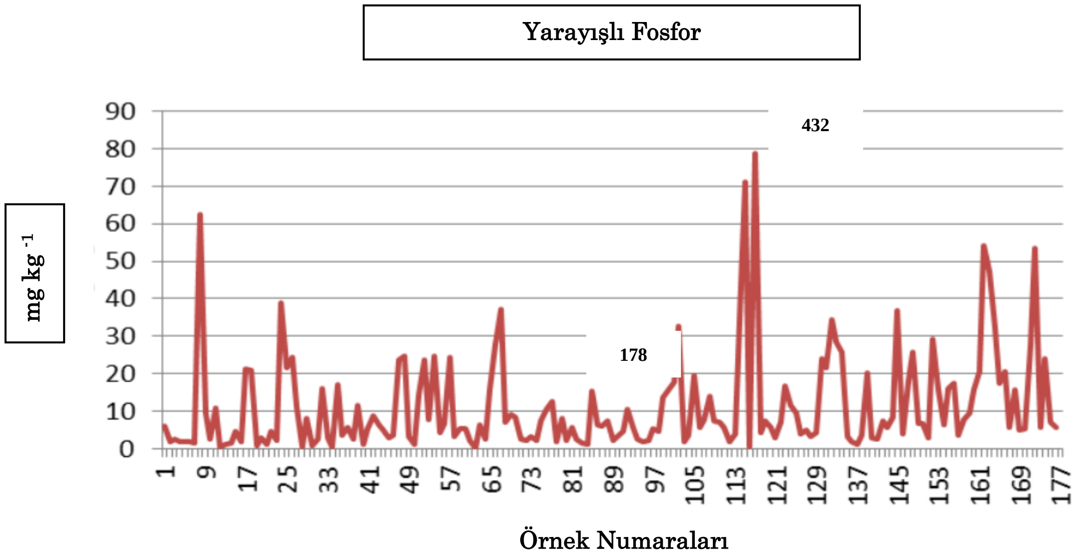
BULGULAR ve TARTIŞMA

0-30 cm deriliğinde YP içeriklerine göre en yüksek değer 334 numaralı örnekten, 77.1 mg kg^{-1}, en düşük değer 592 numaralı örnekten, 5.1 mg kg^{-1} olarak belirlenmiştir. YP içerikleri en düşük sonuçlar 592, 554, 552, 469 ve 183, en yüksek 669, 632, 432, 487 ve 334 numaralı toprak örneklerinde belirlenmiştir. Ortalama YP değeri 31.5 mg kg^{-1} olarak ölçülmüştür (Şekil 4). Yüksek ve düşük değerler arasındaki farklılıklar tarımsal faaliyetlerin yoğunlaşması ile fosforlu gübrelemenin artması, özellikle 0-30 cm derinliğine uygulanmasından kaynaklandığı düşünülmektedir.



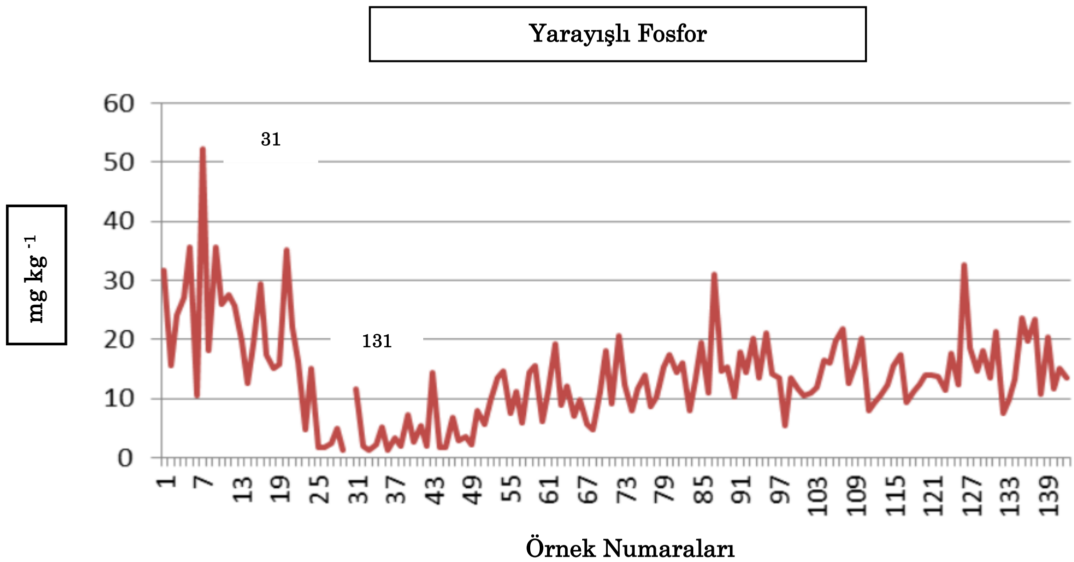
Şekil 4. 0-30 cm toprak derinliğindeki toprakların yarayışlı fosfor değerleri (mg kg^{-1}).
Figure 4. *Useful phosphorus values of soils at a soil depth of 0-30 cm (mg kg^{-1}).*

30-60 cm derinliğinde YP içerikleri bakımından en yüksek değer 432 numaralı toprak örneğinden 78.7 mg kg^{-1}, en düşük sonuç 178 numaralı toprak örneğinden 0.1 mg kg^{-1} olarak belirlenmiştir (Şekil 5), ortalama YP içeriği 13.9 mg kg^{-1} olarak belirlenmiştir. YP içeriği en yüksek değerler 712, 629, 432, 407 ve 31, en düşük değerler 178, 54, 104, 97 ve 431 numaralı toprak örneklerinde saptanmıştır.



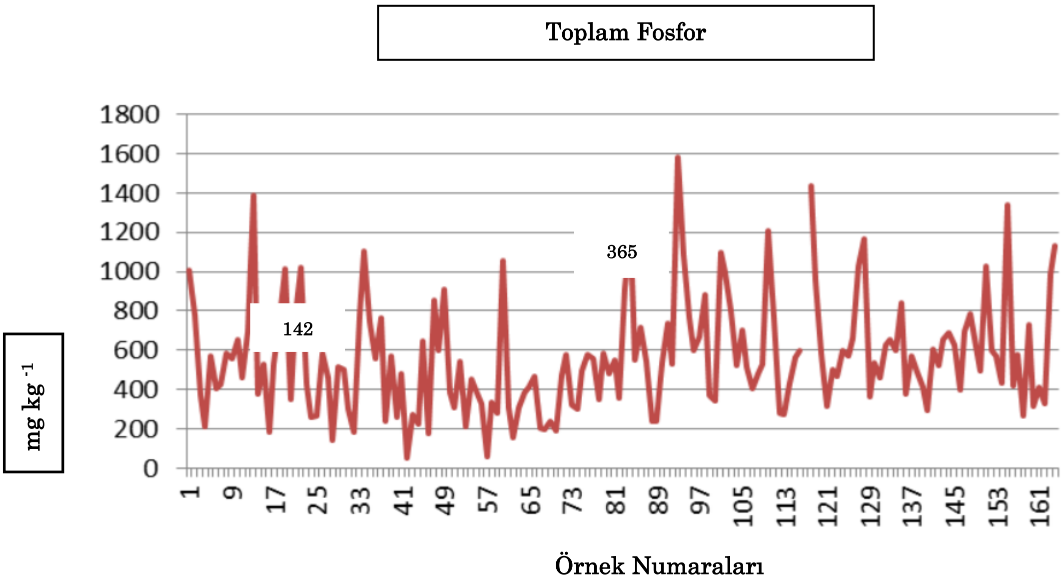
Şekil 5. 30-60 cm toprak derinliğindeki toprakların yarayışlı fosfor değerleri (mg kg^{-1}).
Figure 5. *Useful phosphorus values of soils at 30-60 cm soil depth (mg kg^{-1}).*

60-90 cm derinliğinde YP içerikleri bakımından en yüksek değeri 31 numaralı toprak örneğinden 52.3 mg kg^{-1}, en düşük değeri 131 numaralı toprak örneğinden 1.15 mg kg^{-1} (Şekil 6), ortalama YP düzeyi 11.2 mg kg^{-1} olarak belirlenmiştir. YP içeriğinin en yüksek değerleri 627, 74, 54, 31 ve 28, en düşük değerleri 171, 139, 135, 131 ve 104 numaralı toprak örneklerinde saptanmıştır.



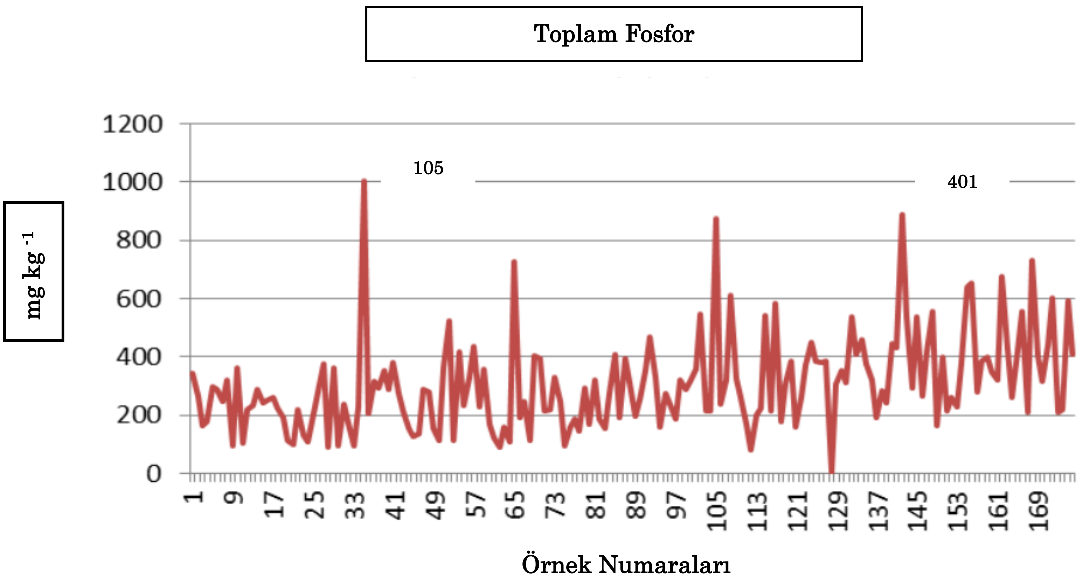
Şekil 6. 60- 90 cm toprak derinliğindeki toprakların yarayışlı fosfor değerleri (mg kg^{-1}).
Figure 6. *Useful phosphorus values of soils at 60-90 cm soil depth (mg kg^{-1}).*

0-30 cm derinliğinde TP içeriği en yüksek değer, 365 numaralı toprak örneğinden 1582.3 mg kg^{-1}, en düşük değer 142 numaralı toprak örneğinden 52,6 mg kg^{-1} olarak belirlenmiştir (Şekil 7). Ortalama TP içeriği 555.9 mg kg-1 belirlenmiştir. TP değerleri en yüksek 666, 507, 470, 365 ve 61, en düşük 183, 178, 147, 142 ve 107 numaralı toprak örneklerinde saptanmıştır.



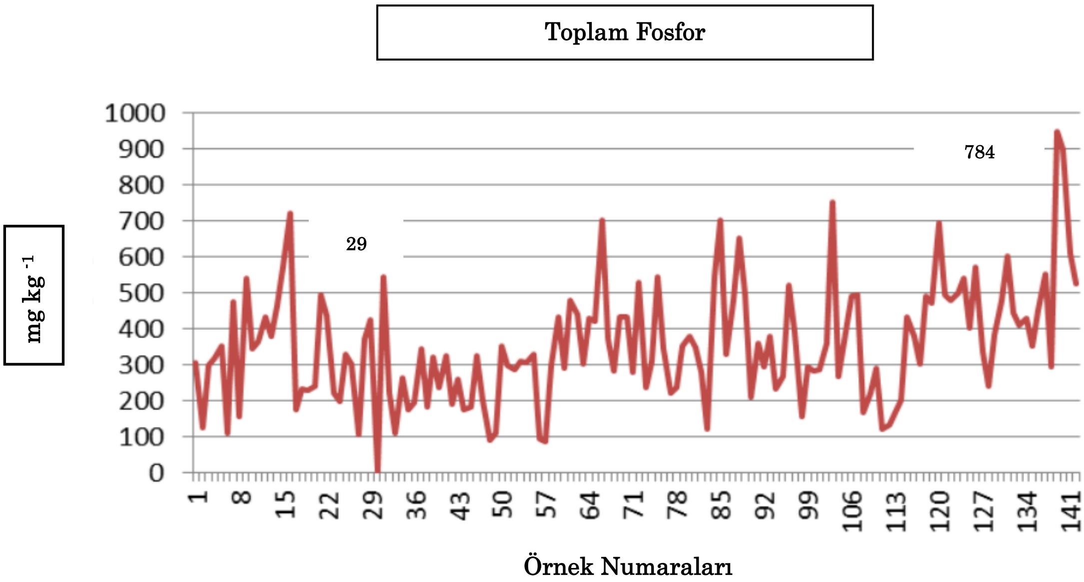
Şekil 7. 0-30 cm toprak derinliğindeki toprakların toplam fosfor değerleri (mg kg^{-1}).
Figure 7. *Total phosphorus values of soils at a soil depth of 0-30 cm (mg kg^{-1}).*

30-60 cm toprak derinliğinde TP içeriği en yüksek değeri 105 numaralı toprak örneğinden 1004.5 mg kg^{-1}, en düşük değeri 401 numaralı toprak örneğinden 80.6 mg kg^{-1} (Şekil 8), ortalama TP değeri 354.4 mg kg^{-1} olarak belirlenmiştir. TP değeri açısından en yüksek değerler 670, 545, 360, 181 ve 105, en düşük değerleri 401, 215, 178, 103 ve 97 numaralı toprak örneklerinde saptanmıştır.



Şekil 8. 30-60 cm toprak derinliğindeki toprakların toplam fosfor değerleri (mg. kg^{-1})
Figure 8. *Total phosphorus values of soils at a soil depth of 30-60 cm (mg kg^{-1}).*

60-90 cm derinliğinde TP içeriği en yüksek değer, 784 numaralı toprak örneğinden 950.4 mg kg^{-1}, en düşük değeri 29 numaralı toprak örneğinden 85.3 mg kg^{-1} (Şekil 9), ortalama TP değeri 306.1 mg kg^{-1} olarak belirlenmiştir. TP içeriği en yüksek; 785, 784, 484, 265 ve 65, en düşük değerleri 218, 216, 179, 129 ve 29 numaralı toprak örneklerinde saptanmıştır.



Şekil 9. 60-90 cm toprak derinliğindeki toprakların toplam fosfor değerleri (mg kg^{-1}).
Figure 9. *Total phosphorus values of soils at a soil depth of 60-90 cm (mg kg^{-1}).*

İrik (2013), Develi Ovasında yaptığı çalışmada, toprak örneklerinin pH ve EC durumlarına göre, 0-30 cm derinlikte en düşük EC değeri 0.25 dS m^{-1}, en yüksek 110.1 dS m^{-1}, ortalama 6.70 dS m^{-1} olarak ölçülmüştür. En düşük pH değeri 6.80, en yüksek 9.96, ortalama 8.35 olarak ölçülmüştür. 30-60 cm derinlikte en düşük EC değeri 0.25 dS m^{-1}, en yüksek 110.1 dS m^{-1}, ortalama 7,50 dS m^{-1} olarak ölçülmüştür. En düşük pH değeri 5.75, en yüksek 9.8, ortalama 8.50 olarak ölçülmüştür. 60-90 cm derinlikte en düşük EC değeri 0.31 dS m^{-1} ve en yüksek 110.1 dS m^{-1}, ortalama 7.45 dS m^{-1} olarak ölçülmüştür. En düşük pH değeri 7.30, en yüksek pH değeri 9,88, ortalama 8.11 olarak ölçülmüştür. Düşük YP değerlerinin belirlendiği bölgelerde pH'nın 8-8,5 civarında, EC'nin yaklaşık 8-16 dS m^{-1} aralığında olduğu saptanmıştır. Bu sonuçlara göre örnekleme noktalarından alınan toprak örneklerinin yüksek pH değerlerinin etkisiyle fosforun çözünemez formlarda bileşikler oluşturduğu ve YP değerlerini olumsuz etkilediği düşünülmektedir.

Reddy ve ark., (1998) yaptıkları çalışmada, toprak da var olan mevcut fosfor içeriğinin 0-30 cm toprak derinliğinde daha yüksek olduğunu ayrıca toprak derinliği arttıkça bu mevcudiyetin düştüğünü vurgulamışlardır. Sönmez ve Pınar (2018)'in yaptıkları çalışmada da benzeri sonuçlar tespit edilmiştir.

SONUÇ

Tarımsal üretimin devamlılığı ve elde edilen ürünlerin kalitesinin sağlanması için bitkinin ihtiyaç duyduğu özellikle makro besin elementlerinden biri olan fosforun bitki tarafından alınabilir durumda olması gerekmektedir. Toprak pH' sına bağlı olarak özellikle pH'ın 8 üzeri olduğu topraklarda fosfor çözünemez bileşikler meydana getirmektedir. Bunun sonucunda tarımsal üretimin ana maddesi olan toprak kaynaklarından fosfor elementi bitki tarafından alınamamaktadır. Develi Ovası'ndan alınan toprak örneklerinden TP düzeyi en yüksek 365 numaralı örnek (0-30 cm) ile 1582.346 mg kg^{-1} ve YP düzeyi 22.29 mg kg^{-1} olarak saptanmıştır. Develi Ovası'ndan alınan 0-30 cm, 30-60 cm ve 60-90 cm' den alınan toprak örnekleri karşılaştırıldığında, TP'nin YP' ye oranına göre en yüksek değer 30-60 cm toprak derinliğinde 27.3 mg kg^{-1} olarak hesaplanmıştır. TP'nin YP' ye oranına göre en düşük değer 60-90 cm toprak derinliğinde 17.6 mg kg^{-1} olarak hesaplanmıştır. Alınan toprak örneklerinde en yüksek TP değeri 0-30 cm derinliğindeki 365 numaralı örnekte tespit edilmiştir. TP içeriğinin 0-30 cm derinliğinde daha yüksek çıkmasının sebebi, fosforlu gübrelerin çoğunlukla yaklaşık olarak 0-30 cm'e verilmesinden ve rizosfer bölgesinde yani toprak derinliğinin yaklaşık 0-30 cm olduğu derinlikte mikroorganizma aktivitesine bağlı olarak diğer derinliklere göre yüksek değer içerebileceği düşünülmektedir. En yüksek YP değeri 30-60 cm derinliğindeki 432 numaralı örnekte tespit edilmiştir. YP içeriğinin genel olarak TP'den düşük olması pH'nın yüksek olması, kireç içeriğinin yüksek olması gibi faktörlerle yararlanılamayan formlarda olmasından kaynaklanabileceği, toprak içeriğine bakıldığında YP miktarı yeterli değil ise gerekli düzeyde parça parça fosfor verilerek fosfor kaybını minimum düzeyde tutmak amaçlanmalıdır. Gerekli düzeyde YP miktarı var ise bu alanlarda fosforlu gübreleme sadece destekleme amaçlı yapılmalı, fazla gübrelemeden kaçınılmalıdır. Toprakta mevcut YP ve TP düzeylerinin yapılan çalışmada belirtildiği üzere toprak derinliğine, tarımsal kullanım ve toprak işlemeye, sıcaklık değişikliklerine ve pH değişikliklerine bağlı olarak değiştiği saptanmıştır.

ÇIKAR ÇATIŞMASI

Yazarlar herhangi bir çıkar çatışması olmadığını beyan ederler.

YAZAR KATKISI

Yazarlar olarak makaleye aşağıdaki katkıların sunulduğunu beyan ederiz.
Yağmur Yılmaz: Çalışmanın gerçekleştirilmesi verilerin ortaya koyulması
Fatma Nur Kılıç: Literatür taraması, makalenin genel kontrolü
Osman Sönmez: Verilerin incelenmesi, makalenin son şeklinin verilmesi

ETİK KURUL KARARI

Bu makale Etik Kurul Kararı gerektirmemektedir.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1173443

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 338-356

Research Article

Effects of Drying Temperature on the Drying Characteristics of Parboiled Palm Nuts

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ABSTRACT

The effect of drying temperature on drying characteristics of cooked and fermented palm nuts were determined. The samples were processed using two methods (cooking and fermentation). The rate of drying the samples was observed to increase with corresponding increase in temperature and drying time. It was duly observed that at 70°C, Tenera sample (TS), Pisifera sample (PS) and Dura sample (DS) attained their constant drying rates at 720 mins, 600 mins, and 780 mins. At 80°C TS, PS and DS drying rates falls to zero at 660mins, 600 mins and 720 mins, for 90°C drying temperature, TS and PS had same constant drying rate at 540 mins, DS constant drying rate was found at 600mins. For 100°C TS constant drying rates was observed at 480mins while PS and DS had same constant drying rate at 420mins respectively. The effective drying of the samples was observed to occur at falling rate across the varieties and processing methods. The lower temperature (70°C) decreased the drying rates while the higher temperature increased the drying rates. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440 mins at temperature range of 70-100°C respectively. The regression equations were found to give the best fit with highest coefficient of variation (R^2) values. Mostly all the samples irrespective of processing methods exhibited quadratic regression equations. The cooked samples displayed better dry characteristics than fermented samples.

RESEARCH ARTICLE

Received: 15.09.2022
Accepted: 22.11.2022

Keywords:

- Palm nuts,
- Drying,
- Fermentation,
- Cooked,
- Temperature

To cite: Godson EE, Oluka I and Ide PE (2022). Effects of Drying Temperature on the Drying Characteristics of Parboiled Palm Nuts. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 338-356.* https://doi.org/10.46592/turkager.1173443

INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the most important economic tree crops in Nigeria. The global growing demand for palm oil and its products is making oil palm cultivation a necessary means of livelihood for many rural families, and indeed the farming culture of millions of people in Nigeria. The oil palm tree is a useful crop that is relevant in all aspects of life with socioeconomic and socio-cultural values. According to Ibitoye *et al.* (2011), oil palm is a versatile tree crop with almost all parts having economic value and useful for everyday livelihood. The different parts of oil palm include: the fronds, leaves, trunk and roots. These parts give a wide range of products which are of benefit to mankind. The importance of oil palm to the national economy of Nigeria cannot be over emphasized. It ranges from production of food for human consumption, employment, income to farmers and nation and raw materials for industries. Oil palm has been a major source of foreign exchange to Nigeria as well as source of revenue to major segment of the rural population of Southeast Nigeria (Onoh and Peter-Onoh, 2012). The most important product of oil palm is the palm fruit, which is processed to obtain three commercial products namely: palm oil, palm kernel oil and palm kernel cake. Palm oil and palm kernel oil are two distinct oils which are important in World Trade (Barcelos *et al.*, 2015). Hence, oil palm is often referred to as a crop of multiple values, which underscores its economic importance (Akangbe *et al.*, 2011). It has been established in literature that the domestic consumption of palm oil in Nigeria, in 2017/2018, amounted to about 1.29 million metric tons (Conway, 2018). Palm oil is used in the manufacturing of margarine, soap candle, base for lipstick, waxes and polish bases in a condense form, confectionary (Embrandiri *et al.*, 2011). Oil palm is a monocotyledonous plant belonging to the palm family Arecaceae. It is a monoecious species known to produce unisexual male and female inflorescences in an alternating cycle (Barcelos *et al.*, 2015). Oil palm is, no doubt, the richest tree on earth in terms of natural endowments. It is one of the best trees given by God to man in the tropics for his survival and for all his vegetable oil and related needs. It has been described as the 'tree of life' not only because every part of the tree is useful to man but also because it lives and flourishes for many years. At present, oil palm produces the highest yield (output per land area) of vegetable oil of all known oil crops (Corley and Tinker, 2007). The three main varieties of the oil palm distinguished by their fruit's characteristics are Dura, Pisifera and tenera (Stephen and Emmanuel, 2009). Dura: this has a very thin pericarp, 40-70% of fruit weight with very little and a very big shell of about 2-5 mm thickness. The kernel size is generally bigger than other varieties. Tenera: this has a thick pericarp of about 60% fruit weight very high oil and thick shell (1-2.5 mm) which promotes easy cracking. Pisifera: this has a thicker pericarp with higher oil yield with little or no kernel.

Drying characteristics is the commonest agricultural products processing employed in improving agro-products stability and security, as far as it noticeably declines the negative effect of water in the material, deterioration, microbiological activity, physical and chemical changes during its processing and storage (Mujumdar and Law, 2010). It also, causes colour change, weight reduction, and enhances aesthetic and sensory effects of biomaterials (Brennan, 2006). Therefore, the basic goal is to limit moisture content to levels that halt or slow down the growth of spoilage microorganisms and incident of chemical reactions in order to extend the shelf-life of food (Oduro *et al.*, 2007). According to Maskan (2001) the high quality fast-dried foods have become necessary in the recent times which aggravated a renewed interest in drying operations. Furthermore, there is a high demand for convenient foods more especially ready to eat and instant products, which are desired to contain the less contents of additives and preservatives (Mujumdar and Law, 2010). In spite of the different physical processes used in various drying methods, the underlying principles are very similar, with few exceptions. Several drying systems have been reported by several researchers but were mostly solar dryers depending on climatic conditions (Alonge and Hammed, 2007; Folaranmi, 2009; Alonge, 2008; Amer *et.al.,* 2009; Gatea, 2010). Some electric dryers have also been constructed but were mostly for grains and tuber crops. Therefore, the interest of the research was to determine the effects of drying temperature on the drying characteristics of parboiled and fermented palm nuts.

MATERIALS and METHODS

Source of sample

The samples Dura, Tenera and Pisifera used for this experimental work were all sourced from Enugu East Local Government Area of Nigeria, at harvest moisture content. The latitude of Enugu East, Enugu, Nigeria is 6.489472, and the longitude is 7.517159. Abakpa, Enugu, Nigeria is located at Nigeria country in the Towns place category with the GPS coordinates of 6° 29' 22.0992'' N and 7° 31' 1.7724'' E.

Preparation of the sample

The palm, fruits of Dura, Tenera and Pisifera varieties were harvested from palm-oil processing mill farm located at Enugu East Local Government Area, Enugu State Nigeria. The harvested palm fruits varieties were debouched, and the fruits are detached from their parent stalk and parked in a local basket. The detached fruits were further wiped with a wet clean cloth to removed dirty, dust, broken nuts and nonviable nuts. Each variety were divided into two equal batches, first batch and second batch were subjected to 72 hours fermentation and parboiling which are two pre-treatment methods used. The fermented and parboiled sample were further divided into four equals. The first, second, third and fourth batches were dried to constant weight/moisture using 70, 80, 90 and 100°C drying temperature at interval of 1 hour. The drying characteristics of the processed samples were determined.

Experimental methods

Drying kinetic of palm nut

Drying kinetics reveal the detailed information about the drying process of trifoliate yam slices (John *et al.,* 2020). Their parameters are determined using the following formula.

Moisture content at any time of drying

The moisture content of the sample at any given time and condition were determined using the equation reported by (Chineze *et al.,* 2020):

$$M_{ct} = \frac{W_t - W_d}{W_t} \tag{1}$$

Where:
M_{ct} = Moisture content (%wt)at time t;
W_t = Initial weight of the sample at any time
W_d = Weight of the dried sample

Drying rate at any time of drying

The drying rate of the sample were determined using the equation reported by Dai *et al.* (2017) with little modification.

$$D_R = \frac{M_{t1} - M_{t2}}{t_2 - t_1} \qquad (2)$$

D_R = Drying rate (% h)
M_{t1} = Moisture content of drying basis at t_1, (g g^{-1})
M_{t2} = Moisture content of drying basis at t_2 (g g^{-1})
t_2 = Time of drying at M_{t2}
t_1 = Time of drying at M_{t1}

Moisture ratio

Moisture ration of the samples were determined using the equation reported by Dai *et al.* (2017) with little modification.

$$M_R = \frac{M_{t1}}{M_0} \qquad (3)$$

M_R = Moisture ratio
M_{t1} = Moisture content of dry basis at any time
M_0 = Initial dry moisture content of the sample.

Statistical analysis

The experiment was carried out in a completely random design. The results obtained were submitted to analysis of variance (ANOVA), with the means compared by Duncan's test at 5% of significance. All results were expressed as the mean value standard error (SE). Statistical analyses were performed using SPSS for Windows 8.0.

RESULTS AND DISCUSSION

Data presentation/analysis

The data collected from this study was analysed using tables, graphs and statistical method.

Drying characteristics is generally determined experimentally by measuring the weight of a drying sample as a function of drying time, drying temperature and moisture content reduction (Saeed *et al.*, 2008). The drying curves which indicate the rate of change in moisture content during drying process of cooked and fermented palm kernel varieties are presented in table 1&2 and from Figure 1 to Figure 8. The curve is important as it indicates the time the drying of the samples should stop at required moisture content to ensure a good quality product. It is obvious that as the drying time increases, the moisture content of the sample decreased.

Table1. Drying characteristics of cooked palm kernel varieties dried at varied temperature 70°C, 80°C, 90°C and 100°C using oven drying method.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	23.64	34.72	26.36	23.64	34.72	26.36	23.64	34.72	26.36	23.64	34.72	26.36
60	19.61	26.04	22.16	20.01	24.72	24.42	18.46	26.62	21.01	19.81	19.64	11.84
120	13.14	18.24	19.18	15.18	20.16	19.94	14.28	18.15	14.26	13.13	9.83	7.43
180	9.74	13.44	15.42	10.64	12.83	16.47	10.82	12.64	10.01	8.48	5.84	3.46
240	6.12	10.52	12.16	5.94	9.45	10.89	5.47	9.47	5.64	3.86	3.27	1.61
300	4.78	8.61	9.28	3.93	6.12	7.14	3.88	5.44	3.26	1.61	1.24	1.05
360	3.48	5.82	6.41	2.15	4.01	5.94	1.16	2.99	2.12	1.14	1.01	1.04
420	2.04	3.04	4.24	1.82	2.81	4.11	1.17	1.84	1.34	1.09	1.01	1.04
480	1.71	2.24	2.18	1.42	2.10	2.72	1.07	1.10	1.04	1.09	0.00	0.00
540	1.52	1.16	1.14	1.26	1.18	1.95	1.07	1.10	1.02	0.00	0.00	0.00
600	1.31	1.16	1.10	1.04	1.18	1.31	0.00	0.00	1.02	0.00	0.00	0.00
660	1.17	0.00	1.02	1.04	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
720	1.17	0.00	1.01	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

Table 2. Drying characteristics of fermented palm kernel varieties dried at varied temperature 70°C, 80°C, 90°C and 100°C using oven drying method.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	11.95	20.07	14.63	11.95	20.07	14.63	11.95	20.07	14.63	11.95	20.07	14.63
60	10.20	15.82	12.3	10.40	12.32	11.63	7.00	9.64	11.3	9.41	8.18	9.61
120	9.60	12.28	10.96	7.70	10.30	9.41	4.28	4.54	7.31	5.20	5.61	4.74
180	8.30	9.92	9.86	7.10	7.20	7.15	2.01	2.48	3.71	3.01	2.13	2.48
240	7.60	5.65	8.41	6.50	5.40	4.18	1.06	1.27	3.02	1.68	1.14	1.96
300	6.40	4.81	9.64	5.80	3.74	2.88	1.02	1.04	2.61	1.41	1.12	1.36
360	6.20	3.74	5.02	4.70	1.87	1.96	1.01	1.03	1.71	1.17	1.06	1.19
420	4.17	2.24	3.84	2.01	1.31	1.48	1.01	1.03	1.16	1.16	1.03	1.07
480	3.60	1.76	2.21	1.71	1.07	1.28	0.00	0.00	1.06	1.16	1.03	1.03
540	2.02	1.08	1.66	1.61	1.06	1.14	0.00	0.00	1.06	0.00	0.00	1.02
600	1.18	1.04	1.64	1.16	0.00	1.09	0.00	0.00	0.00	0.00	0.00	0.00
660	1.15	1.04	1.15	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00
720	1.15	0.00	1.07	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

From Table 1, the drying curve of cooked palm kernel samples were presented at temperature range of 70°C to 100°C. It was observed also across the drying temperatures tested DS recorded highest drying time apart samples dried under 100°C. Drying curves which measures the pattern at which moisture migrate from the drying samples to the surroundings, showed that all the samples had a good drying curve trend. From Table 2, the TS, PS and DS rate of moisture removal with respect to time was found to constant at 720 mins, 660 mins and 840 mins for 70°C, 600 mins, 540 mins and 720 mins for 80°C, 420 mins, 420 mins and 540 mins for 90°C and 480 mins, 480 mins and 540 mins for 100°C respectively. This Table 2, showed that DS samples consumed more time to attain constant drying rate than other samples irrespective of processing method adopted.

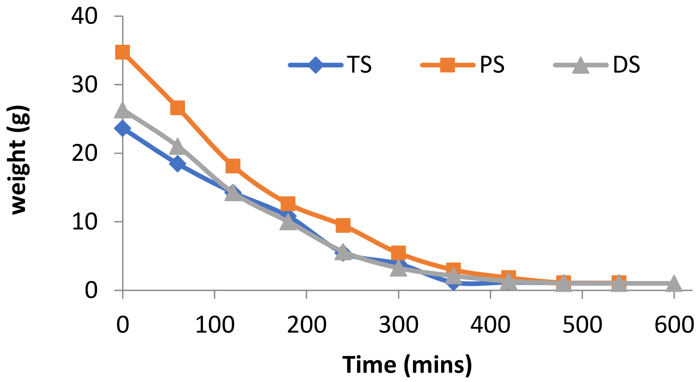

Figure 1. Drying curves for Dura, Tenera and Pisifera cooked samples at 70°C.

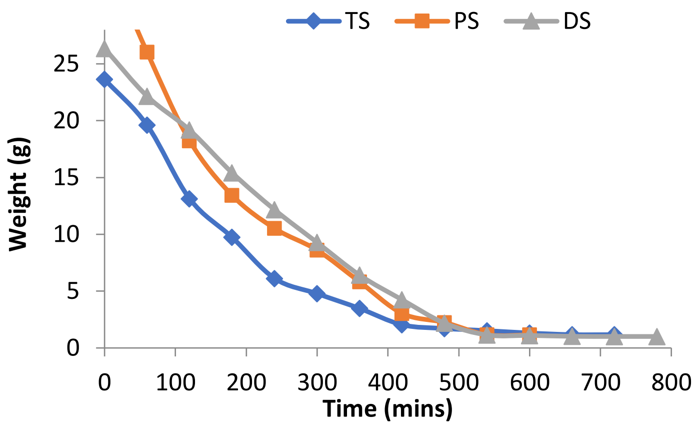

Figure 2. Drying curves for Dura, Tenera and Pisifera cooked samples at 80°C.

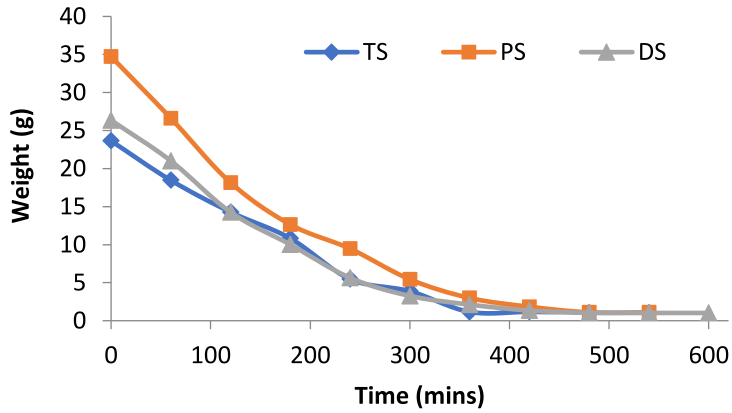

Figure 3. Drying curves for Dura, Tenera and Pisifera cooked samples at 90°C.

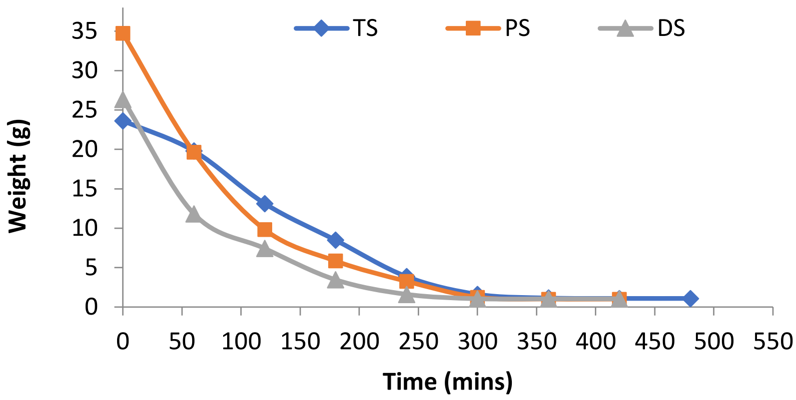

Figure 4. Drying curves for Dura, Tenera and Pisifera parboiled samples at 100°C.

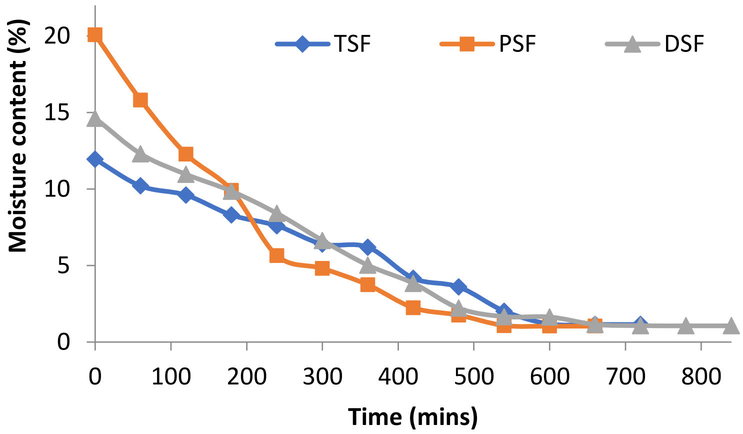

Figure 5. Drying curves for Dura, Tenera and Pisifera fermented samples at 70°C.

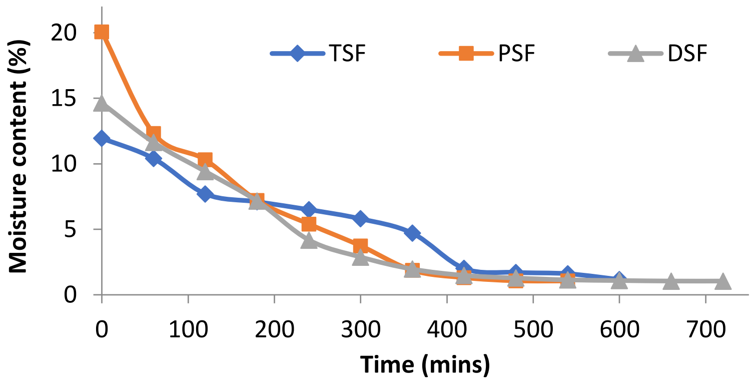

Figure 6. Drying curves for Dura, Tenera and Pisifera fermented samples at 80°C.

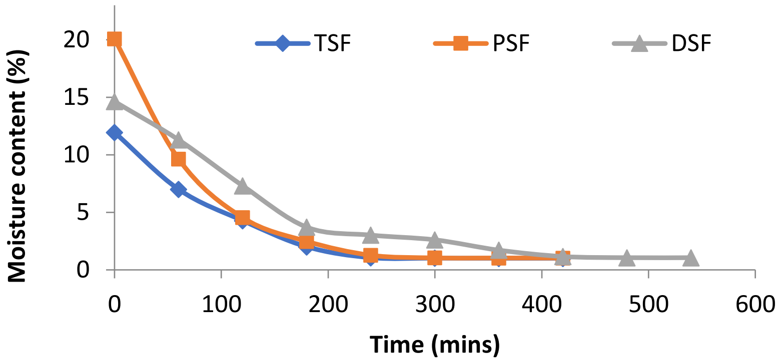

Figure 7. Drying curves for Dura, Tenera and Pisifera fermented samples at 90°C.

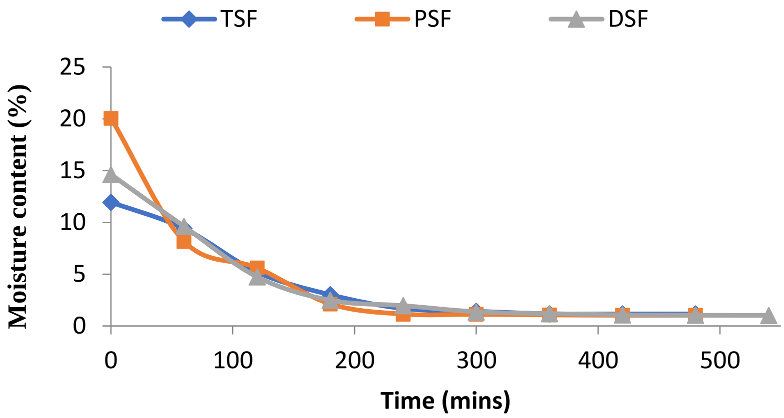

Figure 8. Drying curves for Dura, Tenera and Pisifera fermented samples at 100°C.

Table 3. Relationships between drying curves of tested samples at different moisture contents.

Moisture contents		Regression Equations			
		Cooked		Fermented	
Dura	70	$W_{DS} = 6E-05T^2 - 0.076T + 26.92$	$R^2 = 0.997$	$W_{DSF} = 2E-05T^2 - 0.033T + 14.92$	$R^2 = 0.960$
	80	$W_{DS} = 6E-05T^2 - 0.083T + 28.01$	$R^2 = 0.989$	$W_{DSF} = 5E-05T^2 - 0.050T + 14.46$	$R^2 = 0.989$
	90	$W_{DS} = 0.000T^2 - 0.109T + 26.30$	$R^2 = 0.994$	$W_{DSF} = 8E-05T^2 - 0.064T + 14.31$	$R^2 = 0.977$
	100	$W_{DS} = 0.000T^2 - 0.156T + 23.65$	$R^2 = 0.952$	$W_{DSF} = 9E-05T^2 - 0.069T + 13.37$	$R^2 = 0.948$
Tenera	70	$W_{TS} = 7E-05T^2 - 0.081T + 22.95$	$R^2 = 0.983$	$W_{TSF} = = 6E-06T^2 - 0.020T + 11.86$	$R^2 = 0.984$
	80	$W_{TS} = = 9E-05T^2 - 0.092T + 24.24$	$R^2 = 0.987$	$W_{TSF} = = 1E-05T^2 - 0.026T + 11.72$	$R^2 = 0.970$
	90	$W_{TS} = 0.000T^2 - 0.098T + 24.06$	$R^2 = 0.994$	$W_{TSF} = 0.000T^2 - 0.070T + 11.36$	$R^2 = 0.983$
	100	$W_{TS} = 0.000T^2 - 0.117T + 24.82$	$R^2 = 0.990$	$W_{TSF} = 8E-05T^2 - 0.062T + 12.03$	$R^2 = 0.982$
Pisifera	70	$W_{PS} = 0.000T^2 - 0.119T + 32.95$	$R^2 = 0.988$	$W_{PSF} = 6E-05T^2 - 0.067T + 19.69$	$R^2 = 0.993$
	80	$W_{PS} = 0.000T^2 - 0.128T + 33.28$	$R^2 = 0.992$	$W_{PSF} = = 1E-05T^2 - 0.026T + 11.72$	$R^2 = 0.970$
	90	$W_{PS} = = 0.000T^2 - 0.141T + 34.19$	$R^2 = 0.996$	$W_{PSF} = 0.000T^2 - 0.122T + 18.09$	$R^2 = 0.95$
	100	$W_{PS} = 0.000T^2 - 0.204T + 32.46$	$R^2 = 0.976$	$W_{PSF} = 0.000T^2 - 0.105T + 17.07$	$R^2 = 0.909$

From Figure 1-Figure 8, drying characteristics curves were represented graphically as averaged moisture content versus time (Coumans, 2000; Saeed *et al.*, 2008). It was observed from the Figure 1 to Figure 8, that the fermented samples displayed a better drying curve properties with longer drying time while cooked samples had short drying time and this could be as a result of hardened surface of the fermented samples which prevented free migration of water from the sample during drying (Saeed *et al.*, 2008). The drying rate also indicates the quantity of moisture evaporated per unit time. It was found that at the beginning of drying, there was a higher rate of moisture loss in all the samples and this rate decreased as the drying time increased and this might be as a result of the nature of water present in the sample (Akpinar *et al.*, 2003) or due to internal pressure generated that forces the moisture in vapour from outside the palm kernel samples (Nguyen and Price, 2007).

From Figure 1 - 8 and Table 3 the relationship between change in moisture content and with time are presented. The average values of correlation coefficient (R^2) of the samples which measures the relationship and variation between variables were 0.983, 0.989, and 0.988 for DS, TS, and PS at temperature range of 70-100°C for cooked samples respectively. While DS, TS and PS had average values of correlation coefficient of 0.969, 0.979 and 0.956 for fermented samples at temperature range of 70-100°C respectively. The Table, 3 presented best fit regression equations and it was observed that all the samples displayed quadratic regression equations for both cooked and fermented samples in Table 3. These values of mathematical equation and correlation coefficient are good prediction of the drying basis of moisture value at any time in the drying process and indicated that the mathematical equation best fits the drying processes since their values are very close to 1.

From Table 4 and 5, the moisture ratio was presented, the moisture ration which measures the ratio of water diffusion or migration from a drying sample with respect to time of drying. The ration of water diffusion and migration from the samples during drying were found to be ±0.01 across all the tested samples irrespective of the drying temperatures. For the cooked samples, the moisture ratio at which the water both bounded and unbounded water migrates from the drying samples falls to zero (constant moisture ratio) with respect to drying time were found to be 720 mins (0.096), 660 mins (0.051) and 840 mins (0.072) for TS, PS and DS at 70ºC. For 80ºC the constant moisture ratio were 600 mins (0.097), 540 mins (0.052) and 720 mins (0.071) for TS, PS and DS respectively. For 90°C and 100°C, the moisture ratio attained their constant values with respect to time were observed at 420 mins (0.084), 420 mins (0.054), 540 mins (0.072) and 480 mins (0.097), 480 (0.051), 540 (0.069) for TS, PS and DS respectively. For the fermented samples dried at 70°C and 80°C drying temperature attained constant moisture ratio at 720 mins (0.049), 600 mins (0.033), 720 mins (0.039) and 660 mins (0.044), 600 mins (0.034), 720 mins (0.039) for TS, PS and DS respectively. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440mins at temperature range of 70-100ºC respectively. It could be observed that, at the beginning of drying the ratio of drying with time was controlled by free water on the surface of samples. As the drying time increased, the moisture ratio decreased indicating that water was no longer free, this indicated that the water present in the samples was held by molecular adsorption and capillary condensation

(Dairo and Olayanju, 2012). At this point diffusion-controlled process in the moisture ration occurred, in which the ratio of moisture migration with time limited by the diffusion of water from internal to external part of the samples (Dairo and Olayanju, 2012; Kajuna *et al.*, 2001; Sobukola *et al.*, 2007).

Table 4. Moisture ratio of cooked palm nut samples at temperature range of 70-100°C.

	70⁰C			80⁰C			90⁰C			100⁰C		
TIME	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.853	0.788	0.840	0.870	0.613	0.794	0.585	0.480	0.772	0.787	0.407	0.656
120	0.803	0.611	0.749	0.644	0.513	0.643	0.358	0.226	0.499	0.435	0.279	0.323
180	0.694	0.494	0.673	0.594	0.358	0.488	0.168	0.123	0.253	0.251	0.106	0.169
240	0.635	0.281	0.574	0.543	0.269	0.285	0.088	0.063	0.206	0.140	0.056	0.133
300	0.535	0.239	0.658	0.485	0.186	0.196	0.085	0.051	0.178	0.117	0.055	0.092
360	0.518	0.186	0.343	0.393	0.093	0.133	0.084	0.051	0.116	0.097	0.052	0.081
420	0.348	0.111	0.262	0.168	0.065	0.101	0.084	0.051	0.079	0.097	0.051	0.073
480	0.301	0.087	0.151	0.143	0.053	0.087	0.00	0.00	0.072	0.097	0.051	0.070
540	0.169	0.053	0.113	0.134	0.052	0.077	0.00	0.00	0.072	0.00	0.00	0.069
600	0.098	0.051	0.112	0.097	0.00	0.074	0.00	0.00	0.00	0.00	0.00	0.00
660	0.096	0.051	0.078	0.00	0.00	0.071	0.00	0.00	0.00	0.00	0.00	0.00
720	0.096	0.00	0.073	0.00	0.00	0.071	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	0.072	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	0.072	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

Table 5. Moisture ratio of fermented palm nut samples at selected temperatures.

	70⁰C			80⁰C			90⁰C			100⁰C		
TIME	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**	**TS**	**PS**	**DS**
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.830	0.75	0.841	0.846	0.712	0.926	0.780	0.766	0.797	0.837	0.565	0.449
120	0.556	0.525	0.728	0.642	0.581	0.756	0.604	0.522	0.540	0.555	0.283	0.281
180	0.412	0.387	0.585	0.450	0.369	0.624	0.458	0.364	0.379	0.358	0.168	0.131
240	0.259	0.302	0.461	0.251	0.272	0.413	0.231	0.272	0.213	0.163	0.094	0.061
300	0.202	0.248	0.352	0.127	0.176	0.271	0.164	0.156	0.123	0.068	0.035	0.039
360	0.147	0.168	0.243	0.091	0.115	0.225	0.049	0.086	0.080	0.048	0.029	0.039
420	0.086	0.088	0.161	0.077	0.081	0.156	0.049	0.052	0.050	0.046	0.029	0.039
480	0.072	0.065	0.083	0.060	0.060	0.103	0.045	0.031	0.039	0.046	0.000	0.000
540	0.064	0.033	0.043	0.053	0.034	0.074	0.045	0.031	0.038	0.000	0.000	0.000
600	0.055	0.033	0.042	0.044	0.034	0.049	0.000	0.000	0.038	0.000	0.000	0.000
660	0.049	0.000	0.039	0.044	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000
720	0.049	0.000	0.039	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

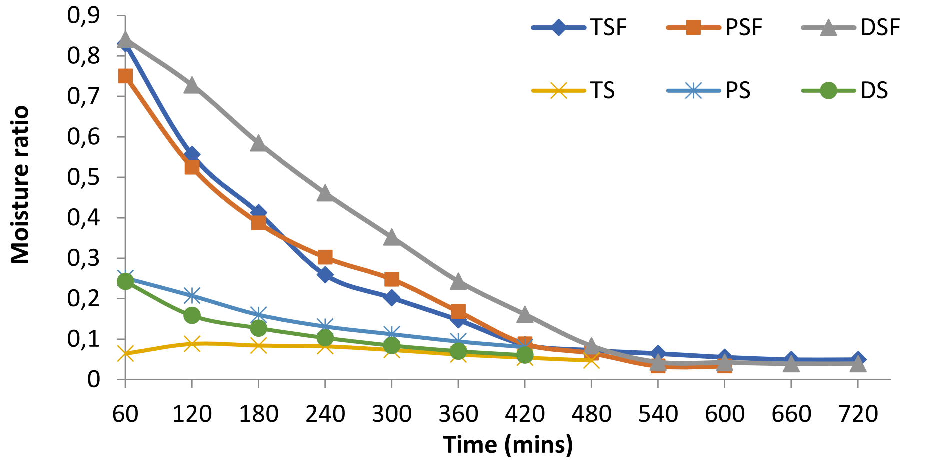

Figure 9. Effect of drying time on moisture ratio of parboiled and fermented samples at 70°C.

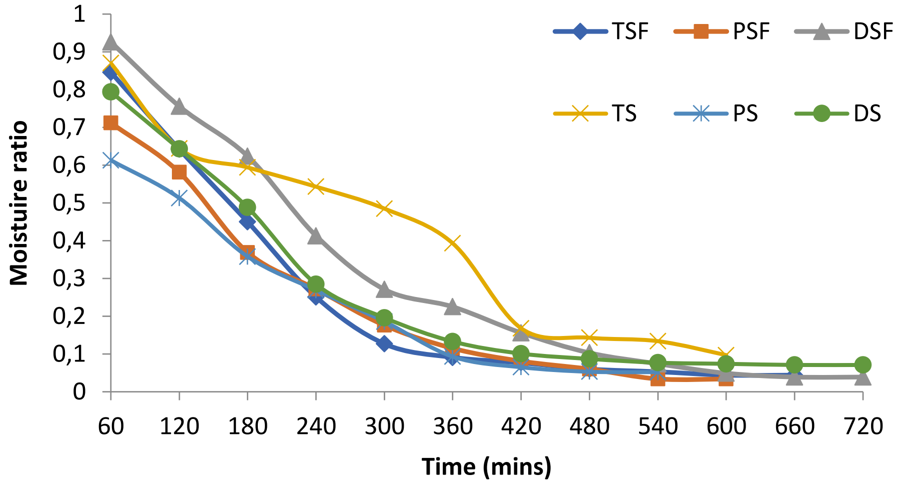

Figure 10. Effect of drying time on moisture ratio of cooked and fermented samples at 80°C.

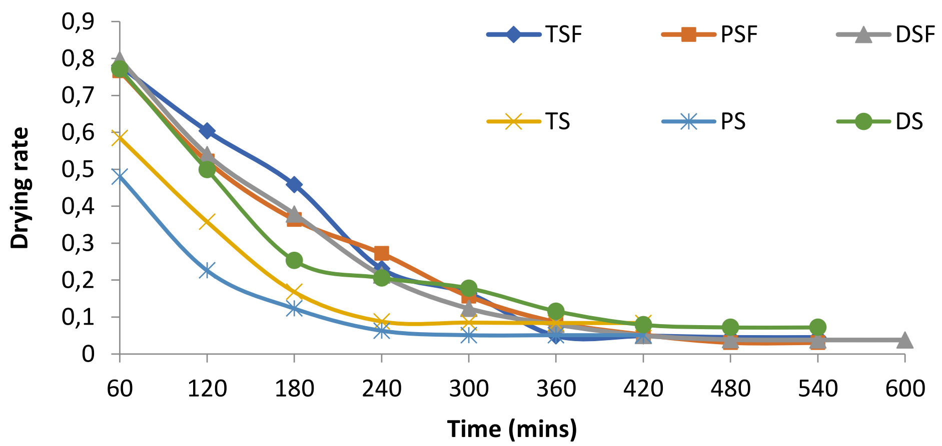

Figure 11. Effect of drying time on moisture ratio of parboiled and fermented samples at 90°C.

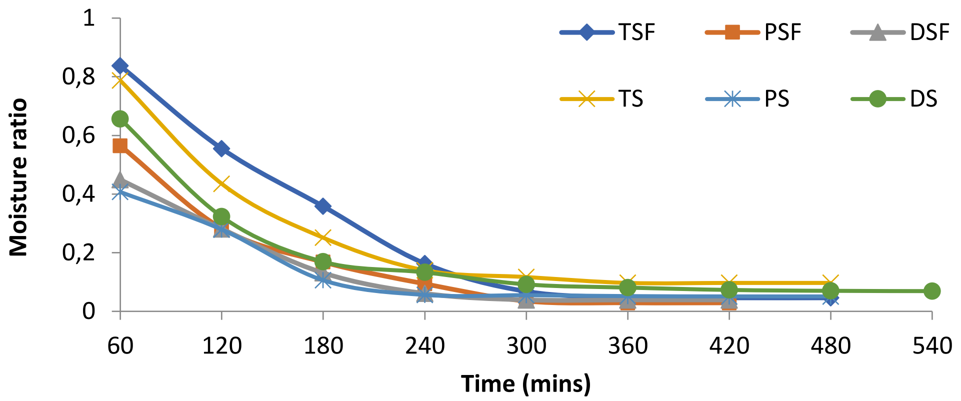

Figure 12. Effect of drying time on moisture ratio of parboiled and fermented samples at 100°C.

From Figure 9 to Figure 12, the moisture ratio at which moisture content leaves the samples were presented graphically. The curves showed that the ratio at which water leaves the samples decreased as the drying time increases, the process continues until equilibrium moisture is attained. It was observed that, at first phase region in the curves there was rapid moisture decrease, accompanied by a falling rate period where the proper drying of agricultural products begins with decrease in moisture removal (Saeed *et al.*, 2008). These findings revealed that diffusion is a physical mechanism governing the moisture movement in the samples (Dairo and Olayanju, 2012).

From Table 6, the drying characteristics equation which describes the relationship between moisture ratio and drying time at 70-100°C. It was observed that, the moisture ratios of fermented and cooked samples at the different drying temperatures were described by best fits regression characteristics equations as shown in Table 6. Most of the samples were seen to exhibit quadratic relationships with time with higher values of coefficient of variation (R^2) which describe the best fit in the regression analysis. As drying progressed, there was decrease in moisture ratio across all samples. There was also decrease in moisture ratio values as temperature increased which corroborates reports of researchers that moisture ratio is greatly influenced by drying temperature and drying time.

Table 6. Drying characteristic equations and relationships between Moisture ratio and drying time of cooked and fermented samples at 70-100°C.

Moisture contents		Regression Equations			
		Cooked		Fermented	
Dura	70	M_R = 0.09ln(t) + 0.609	R^2 = 0.988	M_R = 2E-06t² – 0.003t + 1.04	R^2 = 0.996
	80	M_R = 3E-06t2 – 0.003t + 0.976	R^2 = 0.982	M_R = 3E-06t² – 0.003t + 1.129	R^2 = 0.993
	90	M_R = 5E-06t² – 0.004t + 0.942	R^2 = 0.955	M_R = 4E-06t² – 0.004t + 0.994	R^2 = 0.988
	100	M_R = 5E-06t² – 0.003t + 0.774	R^2 = 0.910	M_R = = 6E-06t² – 0.003t + 0.647	R^2 = 0.990
Tenera	70	M_R =3E-09t³ -3E-06t² +0.000t+0.033	R^2 = 0.970	M_R = 3E-06t² – 0.003t + 0.940	R^2 = 0.973
	80	M_R = 1E-06t² – 0.002t + 0.955	R^2 = 0.950	M_R = 4E-06t² – 0.004t + 1.056	R^2 = 0.980
	90	M_R = 7E-06t² – 0.004t + 0.831	R^2 = 0.980	M_R = 5E-06t² – 0.004t + 1.046	R^2 = 0.990
	100	M_R = = 7E-06t² – 0.005t + 1.019	R^2 = 0.962	M_R = 7E-06t² – 0.005t + 1.146	R^2 = 0.995
Pisifera	70	M_R = 1E-06t² – 0.001t + 0.305	R^2 = 0.997	M_R = -0.32ln(t) + 2.071	R^2= 0.995
	80	M_R = 3E-06t² – 0.002t + 0.795	R^2 = 0.995	M_R = 3E-06t² – 0.003t + 0.901	R^2 = 0 .992
	90	M_R = 6E-06t² – 0.004t + 0.66	R^2 = 0.961	M_R = 4E-06t² – 0.003t + 0.959	R^2 = 0.995
	100	M_R = 4E-06t² – 0.003t + 0.559	R^2 = 0.953	M_R = 4E-06t² – 0.003t + 0.559	R^2 = 0.953

The drying rate indicates the quantity of moisture evaporated per unit time. Akpinar *et al.,* 2003 reported that the nature of water present in the sample determines the rate of moisture loss as drying progresses. Table 7 and table 8 presented the drying rate of palm 350 kernel samples drying at temperature range of 70-100^{0}C. This rate of moisture loss can also be due to internal pressure generated that forces the moisture in vapour form outside the samples. The drying rate decreased continually with drying time for all samples considered. It was observed that the amount of water removed at the initial stage of drying was higher for all temperatures and decreases with time. This was as a result of low internal resistance of moisture at the beginning of drying, in which when energy was impacted, moisture easily moved to the surface where it was evaporated. As the drying progressed, more energy was required to break the molecular bond of the moisture and since constant energy (heat) was supplied, it took longer time to break the bond, therefore drying rate decreased. This agrees with the findings of Ndukwu (2009), who observed that the drying rate was highest at the first hour of continuous drying of cocoa bean. This also was in line with what was reported by other researchers such as Saeed *et al.* (2008), Doymaz, (2011) and Zhao e*t al.* (2016). It was observed that fermented samples had lower drying rates than the cooked samples. This can be attributed to the fermentation process which may have altered the internal structures of the samples and loosened the sample pores thus hastening the free movement of water both on the surface and internal portion in the sample. From the results it was observed that polynomial relationships existed between drying rate and time for fermented samples while mostly quadratic and exponential were obtained for cooked samples. These equations are presented in Table 4-10 and can also be used to model the drying kinetics of the investigated samples.

Table 7. Drying rate of fermented palm nut samples at selected temperatures.

	70^{0}C			80^{0}C			90^{0}C			100^{0}C		
TIME (mins)	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.029	0.071	0.039	0.026	0.129	0.05	0.083	0.173	0.056	0.042	0.198	0.084
120	0.020	0.065	0.031	0.035	0.081	0.044	0.064	0.129	0.061	0.056	0.121	0.082
180	0.020	0.056	0.027	0.027	0.072	0.042	0.055	0.098	0.061	0.050	0.020	0.068
240	0.018	0.060	0.026	0.023	0.061	0.044	0.045	0.078	0.048	0.043	0.079	0.053
300	0.019	0.051	0.017	0.021	0.054	0.039	0.036	0.063	0.040	0.035	0.063	0.044
360	0.016	0.045	0.027	0.020	0.051	0.035	0.031	0.053	0.035	0.030	0.053	0.037
420	0.018	0.042	0.026	0.024	0.045	0.031	0.026	0.045	0.032	0.026	0.045	0.032
480	0.017	0.038	0.026	0.021	0.040	0.028	0.024	0.042	0.028	0.022	0.040	0.028
540	0.018	0.035	0.024	0.019	0.035	0.025	0.000	0.000	0.025	0.022	0.037	0.025
600	0.018	0.032	0.022	0.018	0.033	0.023	0.000	0.000	0.024	0.000	0.000	0.024
660	0.016	0.029	0.020	0.018	0.030	0.021	0.000	0.000	0.000	0.000	0.000	0.000
720	0.015	0.028	0.019	0.017	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
780	0.015	0.000	0.000	0.015	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
840	0.000	0.000	0.000	0.014	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, Dura sample

Table 8. Drying rate of parboiled palm nut samples at selected temperatures.

	70⁰C			80⁰C			90⁰C			100⁰C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.067	0.145	0.070	0.060	0.167	0.032	0.086	0.135	0.089	0.064	0.251	0.242
120	0.088	0.137	0.069	0.071	0.121	0.054	0.078	0.138	0.101	0.088	0.207	0.158
180	0.077	0.118	0.061	0.072	0.121	0.055	0.071	0.123	0.091	0.084	0.160	0.127
240	0.073	0.101	0.059	0.074	0.105	0.065	0.076	0.105	0.086	0.082	0.131	0.103
300	0.063	0.087	0.057	0.069	0.095	0.064	0.066	0.098	0.077	0.073	0.112	0.084
360	0.056	0.080	0.055	0.060	0.085	0.057	0.062	0.088	0.067	0.062	0.094	0.070
420	0.051	0.075	0.053	0.052	0.076	0.053	0.054	0.078	0.060	0.054	0.080	0.060
480	0.046	0.068	0.050	0.046	0.068	0.049	0.047	0.070	0.053	0.047	0.000	0.000
540	0.041	0.062	0.047	0.041	0.062	0.045	0.042	0.062	0.047	0.000	0.000	0.000
600	0.037	0.056	0.042	0.038	0.056	0.042	0.000	0.000	0.042	0.000	0.000	0.000
660	0.034	0.000	0.038	0.034	0.053	0.038	0.000	0.000	0.000	0.000	0.000	0.000
720	0.031	0.000	0.035	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.000	0.000
780	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
840	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, Dura sample

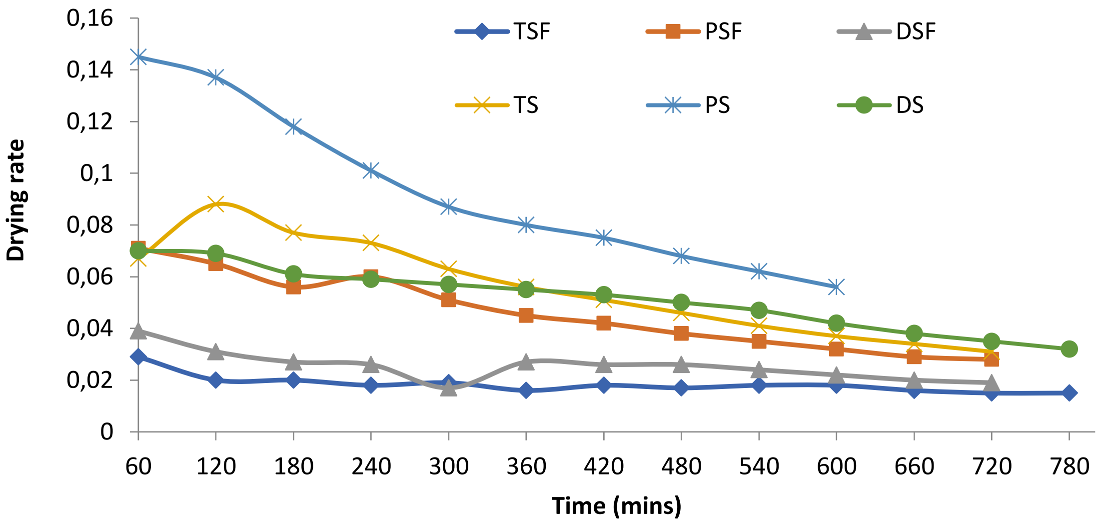

Figure 13. Drying rate of parboiled and fermented samples at 70°C.

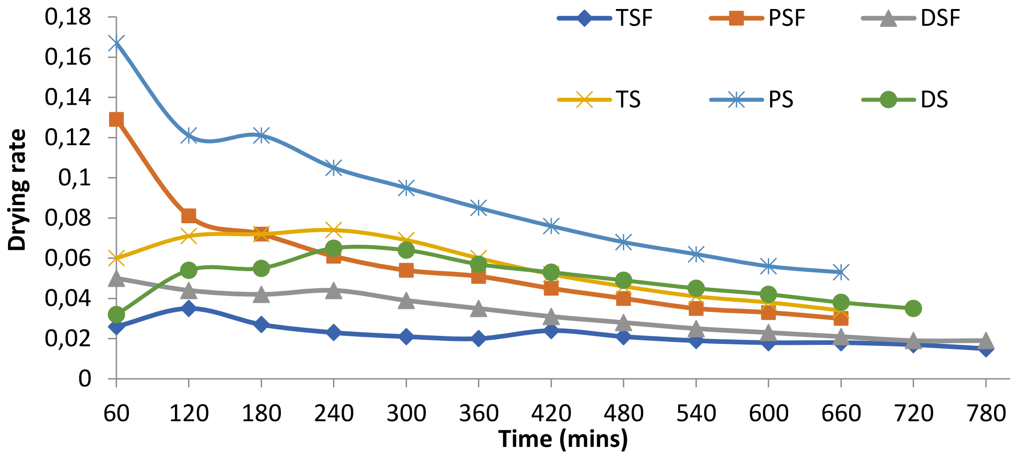

Figure 14. Drying rate of parboiled and fermented samples at 80°C.

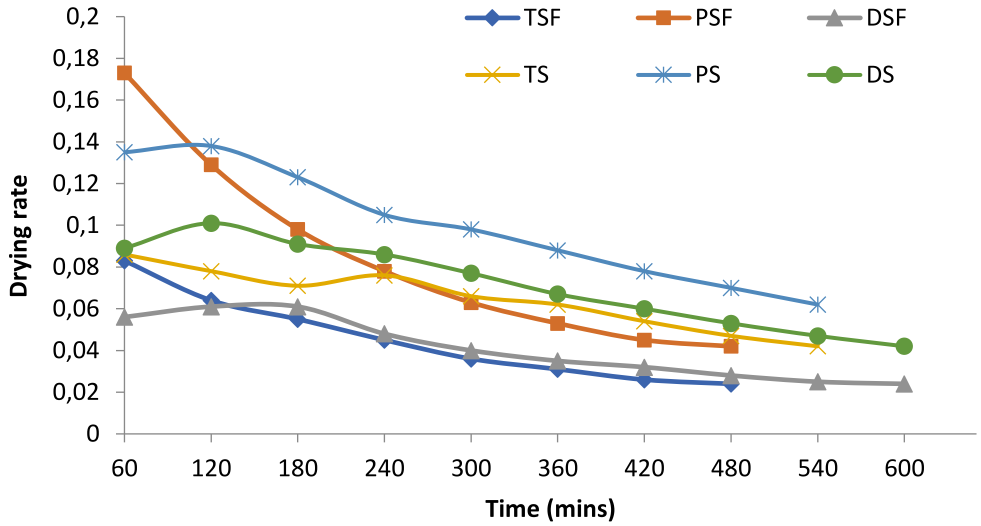

Figure 15. Drying rate of parboiled and fermented samples at 90°C.

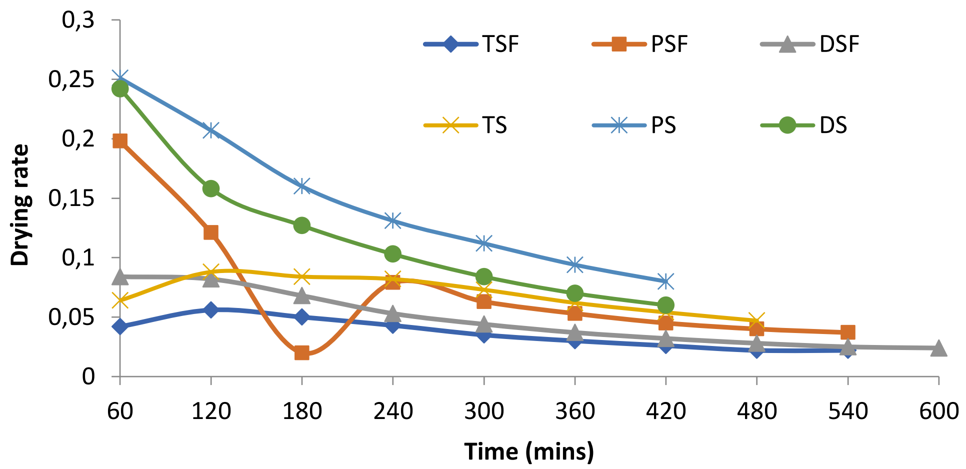

Figure 16. Drying rate of parboiled and fermented samples at 100°C.

The typical effect of initial moisture content on the drying rate across the drying temperature investigated were presented from Figures 13-16. From the curves it was observed that drying rate increased with increased in initial moisture content. This may be as a result of availability of surplus water at the surface of samples for evaporation at higher level which led to higher drying rates. As the drying time increases, movement of water is controlled by diffusion process, the quantity of water to be evaporated at interval reduced drastically. This finding is in agreement with the reports of Dairo and Olayanju, (2012); Sobukola and Dairo, (2007); Hii *et al.* (2008). Also, the drying rate increased with a corresponding increase in temperature from 70 to 100°C. The drying rate at 70°C was observed to be lower than other drying temperatures irrespective of palm kernel varieties and processing methods. This can be attributed to the fact that the samples required more heat to diffuse the core water to pressure the diffusion process. From the Figure 13 to 16, it was noticed that drying rate curves at first phase had enough water to evaporate but as the drying time increased, the quantity of water to be removed decreased at falling rate period.

Table 9. Drying kinetic equations and relationships between drying rate and drying time of parboiled and fermented samples.

Moisture contents		Regression Equations			
		Parboiled		Fermented	
Dura	70	D_R = -5E-05t + 0.073	$R^2 = 0.985$	D_R = 4E-10t³ + 5E-07t² – 0.000t + 0.048	$R^2 = 0.808$
	80	D_R = 7E-10t³ – 1E-06t² + 0.000t + 0.01	$R^2 = 0.942$	D_R = 1E-10t³ – 1E-07t² – 1E-05t + 0.049	$R^2 = 0.983$
	90	D_R = 9E-10t³ – 1E-06t² + 0.000t + 0.083	$R^2 = 0.982$	D_R = 8E-10t³ – 8E-07t² + 0.000t + 0.053	$R^2 = 0.962$
	100	D_R = -7E-09t³ + 6E-06t² – 0.002t + 0.347	$R^2 = 0.993$	D_R = 4E-10t³ – 2E-07t² – 0.000t + 0.096	$R^2 = 0.987$
Tenera	70	$D_R = 0.095\ e^{-0.00t}$	$R^2 = 0.924$	D_R = -2E-10t³ + 2E-07t² – 0.000t + 0.032	$R^2 = 0.865$
	80	$D_R = 0.085\ e^{-0.00t}$	$R^2 = 0.796$	D_R = -2E-11t³ + 4E-08t² – 4E-05t + 0.032	$R^2 = 0.735$
	90	$D_R = 0.096\ e^{-0.00t}$	$R^2 = 0.939$	D_R = -3E-10t³ + 6E-07t² – 0.000t + 0.101	$R^2 = 0.996$
	100	D_R = 3E-09t³ – 3E-06t² + 0.000t + 0.033	$R^2 = 0.970$	D_R = 2E-09t³ – 1E-06t² + 0.000t + 0.030	$R^2 = 0.952$
Pisifera	70	D_R = 2E-07t² – 0.000t + 0.166	$R^2 = 0.991$	$D_R = 0.077\ e^{-0.00}$	$R^2 = 0.986$
	80	D_R = 2E-07t² – 0.000t + 0.174	$R^2 = 0.965$	D_R = -1E-09t³ + 2E-06t² – 0.000t + 0.159	$R^2 = 0.966$
	90	D_R = 4E-08t² – 0.000t + 0.152	$R^2 = 0.978$	D_R = -2E-09t³ + 2E-06t² – 0.001t + 0.228	$R^2 = 0.999$
	100	D_R = 1E-06t² – 0.001t + 0.305	$R^2 = 0.997$	D_R = -7E-09t³ + 7E-06t² – 0.002t + 0.316	$R^2 = 0.838$

Table 9 presented the drying characteristics regression equation and relationship between drying rate and drying time of cooked and fermented samples. The cooked and fermented samples irrespective of sample varieties at temperature range of 70 to 100°C were found to have quadratic relationships apart from cooked Tenera variety which displayed exponential regression equation with respect to drying rate and time. The mathematical equations from these relationships are presented in Table 9 with the coefficient of determination *(R^2)* values. It was also observed that lower temperatures (70 and 80°C) appeared to have fluctuations in the drying curve. Higher temperatures on the other hand appeared to be displayed almost uniform drying rate. Effective drying can therefore be said to take places for all three samples at higher temperatures (falling rates).

CONCLUSION

The effect of temperature and processing methods on drying characteristics of palm kernel were determined. The rate of drying the samples was observed to increase with corresponding increase in temperature and drying time. The effective drying of the samples was observed to occur at falling rate across the varieties and processing methods. The lower temperature (70°C) decreased the drying rates while the higher temperature increased the drying rates. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440 mins at temperature range of 70-100°C respectively. The regression equations were found to give the best fit with highest coefficient of variation *(R^2)* values. Mostly all the samples irrespective of processing methods exhibited quadratic regression equations. The cooked samples displayed better dry characteristics than fermented samples. The results have provided an insight to agricultural and food processors the best method for thermal processing of palm nuts that is time and energy efficient.

DECLARATION OF COMPETING INTEREST

The authors declared that there is no conflict of interest during and afater this research

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Patrıck Ejike Ide: Investigation, formal analysis, writing - original draft, methodology, writing - original draft
Ike Oluka: Methodology, validation and review, and editing.
Eze Godson Ekene: Investigation, writing - original draft, data curation.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1173379

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 357-369

Research Article

Determination of Physicochemical, Cooking and Milling Characteristics of Four Nigerian Rice Varieties

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ABSTRACT

This research work determined the physicochemical, cooking and milling characteristics of four Nigerian rice varieties namely Illa from Southern, Abakaliki South-East, Jemila North and Ofada from West.The physiochemical, milling and cooking properties of rice are solely determining the preference, choice and economy of rice. The four rice varieties grown in different region in Nigeria were investigated for cooking, milling and physical, cooking and chemical characteristics. The result from axial dimension classified all the studied rice varieties as long grains. Illa rice recorded highest value (43.96 g) of 1000 grain weight while lowest value of 20.46 g was observed in Ofada rice. The variation in grain shape were not significant at (P>0.05) and all the tested varieties fall within the slender shapes. All the tested samples displayed good Milling behavior. Ofada rice elongated more than other varieties. The broken percentage was higher and lower in Illa rice (36.72%) and Abakaliki (28.78%) respectively. There were similarities in milling recovering of rice varieties, but Illa had highest expansion (swelling) capacity while Ofada had lowest swelling power. Amylose and gelatinization temperature showed a good relationship, Ofada rice with higher amylose content had lowest gelatinization temperature. The determined cooking time of the rice sample varied from 5.56 to 6.77 mins, Jemila rice will cook faster than other varieties. Illa rice had highest value (353.76%) of water absorption capacity, followed by Abakaliki rice with 185.76% Water Absorption Capacity and Ofada rice which had 158.62% WAC. The lowest value (155.60%) of Water Absorption Capacity was found in Jemila rice variety.

RESEARCH ARTICLE

Received: 16.09.2022
Accepted: 24.11.2022

Keywords:

- Physical properties,
- Cooking characteristics,
- Chemical properties,
- Rice,
- Milling characteristics and varieties

To cite: Ide PE, Ikoko O and Onyeaka H (2022). Determination of Physicochemical, Cooking and Milling Characteristics of Four Nigerian Rice Varieties. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 357-369.* https://doi.org/10.46592/turkager.1173379

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food which has been known as the leading food crop in the globe that is capable of feeding almost half of the global entire population (Pokhrel *et al.*, 2020 ; Singh *et al.*, 2005). Rice is most cultivated crop globally and it's rated as most important crop after wheat (Hettiarachchi *et al.*, 2017). Its origin belongs to the family of Poaceae and it is originated from ancient civilization native to Southeast Asia (Pokhrel *et al.*, 2020; Kim and Shim, 2014). Pokhrel *et al.* (2020) reported that virtually, 90% of the Oryza sativa produced and eaten in Asian whilst other eleven Asian Nations contributed 87% of world Oryza sativa production (Oko *et al.*, 2012). The rice varieties since time immemorial have been produced and consumed after ancient time and has been most helpful in the survival and food security of the world populace (Bhat and Riar, 2017 and Sharma *et al.*, 2020).

The cooked and consumed rice provides about 40% to 80% content of calorie intake among the populace (Tanveer *et al.*, 2016 and Sharma *et al.*, 2020). Some of rice cooking qualities that can be determined in terms of cooking time, elongation of the grains during cooking, major and minor diameter ratio after cooking also determines their economic values of any rice variety (Tanveer *et al.*, 2016). Rice cooking quality attributes solely depends upon on selected properties of starch content such as amylose and amylopectin ratio (Danbaba *et al.*, 2011 and Diako *et al.*, 2011). The most vital its properties of rice which solely influenced rice cooking behavior is amylose content (Ravi *et al.*, 2014 and Xie *et al.*, 2007). According to Tanveer *et al.*, (2016) rice variety with amylose content above 25% reported to absorbs more water and has a fluffy texture during and after cooking. Good rice qualities during and after cooking have been attributed to its linear elongation (Danbaba *et al.*, 2011 and Diako *et al.*, 2011). Rice variety which expands only along its major diameter (length) without corresponding expansion on the minor diameter (girth) is considered high-quality rice (Tanveer *et al.*, 2016). Rice varieties have been proven to have significant effect on their physical, chemical, morphology and cooking properties (Yadav *et al.*, 2007; Siyafutri *et al.*, 2016). According to Putri, (2012) and Han *et al.*, (2008) different cooking method profusely effect the characteristics and hydrolysis of Oryza sativa starch. Rice can be cooked in numerous ways to ensure good quality after cooking. The conventional approach for cooking rice consists of stovetop, boiling and steaming as was described in *liwet* method (Tanveer *et al.*, 2016 and Syafutri, 2015). The modern and conventional way of cooking rice was use of electric device rice-cooker. Each cooking method applied varied heat and cooking time (Larasati, 2012). Previously many authors have reported numerous works on rice more especially on the hysicochemical properties. Recently review of relevant literatures on rice showed that Shin *et al.* (2007); Cantral and Reeves, (2002); Imolehin and Wada, (2000); Prakash and Jamuna (2013); Nádvorníková *et al.* (2018); Pokhrel *et al.* (2020); Megha *et al.* (2019) determined the cooking characteristics and physicochemical properties of different rice varieties as effected by different cooking methods. The review showed that little or no work has been reported on the cooking and physicochemical properties of Nigerian local rice selected from different regions (North, South, West and East) of Nigerian. Therefore, the objective of this research work was to determine the grain qualities characteristics such as cooking properties and physicochemical properties of selected local Nigerian rice varieties.

MATERIALS and METHODS

Source of rice samples

Four locally processed rice varieties Ofada, Jemila, Abakaliki and Illa rice were sourced from DUfarm in Federal University of Agricultural Abeokute Ogun State, Da-Elgreen farm in Chikun Local Government Area Kaduna State, Modern Community Farm in Ministry of Agriculture, Ezzamgbo branch, Ebonyi State and Nature's farm, Illah Ugbolu Local Government Area, Delta State respectively. The mode of selection of the samples were based on variety with highest consumers patronage as revealed by a preliminary consumer survey of local and imported rice varieties sold in the market.

Preparation of the rice samples

The sourced paddy varieties were properly dry-cleaned to remove dirty, immature grain, unwanted and broken materials attached with the samples from the farm. The four locally processed rice varieties (Ofad, Jemila, Abakaliki and Illa) were cooked using the method reported (Alaka *et al.,* 2011). 20g of the samples was weighed into a 250 ml beaker, and 200 ml of water was added to cover it and placed on thermostatically controlled heating mantle at 95°C.

Determination of physical characteristics of rice varieties

Axial dimensions

Major diameter (a), minor diameter (b) and intermediate diameter (c) of the rice samples were determined using vernier caliper with 0.01 mm accuracy. The rice kernels were randomly handpicked and each of their dimensions were determined at three replications.

Thousand weight

One thousand rice kernel were selected randomly from each sample and weighed using Mettler Toledo electronic weighing balance with accuracy of 0.001 g.

Bulk density

Ratio of the mass of rice variety to its measured total volume which referred to as bulk density (ρb). It was determined by following equation (3.1) reported by Tanveer *et al.* (2016).

$$\rho_b = \frac{M_s}{V}\ (kg\ m^{-3}) \tag{1}$$

Where; $M_s$the mass of rice grain, $V$is the volume occupied.

Grain shape

Grain Shape is the major and minor diameter ratio of the locally selected rice varieties, was evaluated using the equation (2) reported as was by Pokhrel *et al.* (2020).

$$Grain\ shape = \frac{a}{b}(mm) \tag{2}$$

Where: a = mean major diameter of milled rice (mm) and b = mean minor of milled rice (mm)

Determination of cooking and milling characteristics of rice

Required Optimum Cooking Time (OCT)

ROCT was measured using the method reported by Pokhrel *et al.* (2020) on evaluation of physicochemical and cooking properties of rice.

Water Uptake Ratio (WUR)

WUR was determined using the method and Equation (3) reported by Pokhrel e*t al.* (2020) on evaluation of physical and chemical and cooking characteristics of rice.

$$Water\ Uptake\ Ratio = \frac{Weight\ of\ kernel\ afer\ cooking\ (g)}{Weight\ of\ kernel\ before\ cooking\ (g)} \tag{3}$$

Elongation Ratio *(ER)*

The elongation ratio *(ER)* was evaluated by the method and Equation (4) reported by Oko *et al.* (2012) on rice cooking quality and physical chemical properties.

$$Elongation\ Ratio = \frac{Average\ lenth\ of\ cooked\ rice\ (mm)}{Avetrage\ length\ of\ uncooked\ rice\ (mm)} \tag{4}$$

Cooked Length *(CL)*

The length of cooked rice and breadth ratio was measured using the Equation (5) reported by Oko *et al.* (2012).

$$Cooked\ length = \frac{Length\ of\ cooked\ rice\ (mm)}{Breath\ of\ cooked\ rice\ (mm)} \tag{5}$$

Dehusking / hulling *(%)*

The hulling percentage of rice sample was determine using the Equation (6) reported by Oko *et al.* (2012).

$$Hulling\ percentage(\%) = \frac{Weight\ of\ brown\ rice\ (g)}{Weight\ of\ rough\ rice\ (g)}\ x\ 100\% \tag{6}$$

Broken Percentage *(BP)*

The broken percentage of the rice kernel varieties were measured using the Equation (7) reported by Ravi *et al.* (2014) on cooking and milling characteristics of rice.

$$Percentage\ broken(PB) = \frac{Weight\ of\ broken\ grain}{Weight\ of\ milled\ sample} x\ 100 \quad (7)$$

Swelling Percentage (*SRI*)

The swelling ratio index of the rice kernel were determined by adopting the Equation (8) reported by Ravi *et al.*, (2014).

$$Swelling\ ratio\ index = \frac{Height\ of\ raw\ rice - height\ of\ cooking\ pot}{Height\ of\ cooked\ rice - height\ of\ ooking\ pot} x\ 100\% \quad (8)$$

Milling recovery

The processed rice was weighed using electronic weighing balance to measure the milling recovery of the rice sample as was reported by Oko *et al.* (2012) and Shaeed *et al.* (2017) as modified by Pokhrel *et al.* (2020) in the Equation (9) below.

$$Milling\ recovery\ = \frac{Weight\ of\ milleed\ rice\ (g)}{Weight\ of\ sample\ paddy\ used\ (g)} x\ 100\% \quad (9)$$

Determination of chemical properties of rice varieties

Amylose and Amylopectin Contents of rice varieties

The amylose content and amylopectin content were all determined by adopting the standard methods reported by Oko *et al.*, (2012).

Gelatinization time and gelatinization temperature at 90°C

The method reported by Alaka *et al.* (2011) was used to determine gelatinization time and gelatinization temperature of the processed rice samples.

Solubility (%)

The solubility of the sample was determined with method reported by Udensi and Onuora, (1992) using Equation (10).

$$Solubility = TSS(\%) \frac{(VsMe - Md)}{2MS1} x\ 100 \quad (10)$$

Vs = Supernatant/ filtrate; *Md*= Empty dish mass; *Me* = Mass of Petri dish plus residual solid after evaporative drying; *Ms* = Mass of flour sample used for preparation of the dispersion.

Water Absorption Capacity

The method of Alaka *et al.* (2011) was used to measured water absorption capacity.

$$WAC(\%) = Final\ Volume\ of\ water - Initial\ Volume\ of\ Water\ Expressed\ incm^3 \quad (11)$$

Statistical analysis

The experiment was carried out in a completely random design. The results obtained were submitted to analysis of variance (ANOVA), with the means compared by Duncan's test at 5% of significance. All results were expressed as the mean value standard error (SE). Statistical analyses were performed using SPSS for Windows 8.0.

RESULTS AND DISCUSSION

Physical properties of rice varieties

The physical properties of grain axial dimensions and weight are of importance to those involved in many aspects of the rice processing industries and these are basic factors to determine rice grain quality. Thomas *et al.* (2013) revealed that physical properties are determined to provide an important data necessarily needed for the design and fabrication of equipment for bulk process and storage of rice varieties.

Table 1. Physical properties of rice varieties.

Properties	Illa	Abakaliki	Jemila	Ofada
Major diameter (mm)	8.34 (0.36)	7.89 (0.26)	7.75 (0.13)	6.88 (0.54)
Minor diameter (mm)	2.40 (0.44)	2.41 (1.41)	2.26 (0.21)	2.05(0.76)
Intermediate diameter (mm)	4.24 (1.43)	4.10 (0.90)	4.00 (2.01)	3.63 (3.09)
1000 grain weight (g)	43.96 (0.62)	36.44 (4.03)	30.00 (2.01)	20.46 (0.67)
Bulk density (g mm^{-3})	18.73 (0.99)	18.61 (0.62)	17.51 (0.48)	20.31 (1.20)
Grain shape	3.47 (0.88)	3.27 (0.65)	3.43 (3.05)	3.35 (0.09)
Porosity (%)	97.02 (0.50)	92.72 (2.50)	89.43 (2.01)	90.49 (0.67)

Note: The values in brackets are standard deviations of the replicated mean values of the samples.

From Table 1, major diameter (length) for Illa, Abakaliki, Jemila and Ofada rice were 8.34 mm, 7.89 mm, 7.75 mm and 6.88 mm, minor diameter (width) for Illa, Abakaliki, Jemila and Ofada were 2.40 mm, 2.41 mm, 2.26 mm and 2.05 mm and intermediate diameter (thickness) were 4.24 mm, 4.10 mm, 4.00 mm and 3.63 for Illa, Abakaliki, Jemila and Ofada rice varieties respectively. From the findings, Illa rice recorded higher value (8.34 mm), followed by Abakaliki rice which had 7.89 mm while Ofada rice had lowest value (6.88 mm) followed by Jemila rice (7.75 mm) of major diameter respectively. The whole rice varieties displayed non significance difference at ($P>0.05$) in terms of minor diameter (width). It is therefore observed that the longest and thicker grain were obtained from Illa rice (8.34mm) while widest were obtained from Abakaliki rice (2.41mm). Categories of rice grains according to Alaka *et al.* (2011) and Dipti *et al.* (2002) reported that grains whose major diameter (length) are longer than 6mm is a long grain, from 5mm to 6mm are medium and less than 5mm is short grain. For these reasons, rice varieties investigated were long grains. Consequently, they have higher market value as width and length of rice measures the rate of demand of rice grain. The major, minor and intermediate diameters characterized grain items of size and shape which varied many other rice properties such as sieving, dehulling, polishing, storage and cooking.

The 1000 grain weight reveals knowledge on the density of the sample. Grains of varied weight milled separately and are likely to retain differently moisture when it is cooked (Megha *et al.*, 2019). Rice grain of same weight is important for consistent grain quality (Megha *et al.*, 2019). The 1000 grain weight were 43.96 g for Illa rice, 36.44 g for Abakaliki rice, 30.00 g for Jemila rice and 20.46g for Ofada rice. Illa rice recorded highest value (43.96 g) of 1000 grain weight while lowest value of 20.46 g was observed in Ofada rice. The weight values of rice samples differ reasonably from each other at ($P<0.05$).

Bulk density (g mm^{-3}) of studied rice varieties were presented in Table 1, The Illa rice had 18.73 g mm^{-3}, Abakaliki rice had 18.61 g mm^{-3}, Jemila rice recorded 17.51 g mm^{-3} and Ofada rice had 20.31 g mm^{-3}. It was observed that Ofada rice samples had highest value (20.32 g mm^{-3}), followed Illa rice which had 18.73 g mm^{-3} of bulk density. Jemila rice had the lowest value (17.51 g mm^{-3}) of bulk density. The results obtained from the bulk density of the samples were similar with the report of Ajatta *et al.* (2016) and Malomo *et al.* (2012) on processed composite flour and yam-soy blend. The bulk density was varied by rice particle size and starch polymer structure. The Jemila rice sample with low bulk density (17.51 g mm^{-3}) are preferred in cooked rice as because it contributed to little dietary bulk, the smooth packaging and transportation of the rice samples (Aluge *et al.*, 2016).

The shape of rice sample length and width ratio) were 3.47 mm for Illa rice, 3.27 mm for Abakaliki rice, 3.43 mm for Jemila rice and 3.35mm for Ofada rice. The varieties were observed to be similar in shape. The variation in grain shape were not significant at ($P> 0.05$). According to the report of Alaka *et al.* (2011), rice sample with ratio greater than 3.0, ration between 2-3 and ratio less than 2 are categorized as slender, bold and round rice respectively. The result presented in the Table 1, revealed that all the investigated rice sample belongs to slender shape rice. It was observed that shape of rice grain varies its volume (Pokhrel *et al.*, 2020), and weight and the slandered rice sample was found to occupy more space than round rice sample during storage. It implies that slender rice varieties occupy more space during storage than same weight of round rice sample (Pokhrel *et al.*, 2020). One of the market values of rice sample is that if round cooked rice is dished with respect to volume instead of weight, the buyer will be advantaged whereas the seller will be favored if it were to be a slender shaped rice variety (Pokhrel *et al.*, 2020 and Alaka *et al.*, 2011). Size and shape of rice varied numerous properties of rice samples such as sieving, polishing, storage as well as cooking characteristics. The consumer preference for rice grain size and shape varied from one group to the other. Alaka *et al.* (2011) reported that higher class people prefer long slender grains whereas lower class people prefer theshort bold grains due its high-volume expansion characteristics. The grain size and shape of most new developed modern rice varieties are classified as slender shaped rice with crystalline appearance.

The table 1, presented the porosity of studied rice varieties. Illa rice had 97.02%, Abakaliki rice had 92.72%, Jemila rice 89.43% and Ofada rice 90.49%. Porosity index of voids was highest in Illa rice 97.02%, and least in Jemila rice 89.43%. Porosity of rice is mainly dependent on its density as bulk density of rice indicates the storage properties (Megha *et al.*, 2019). The bulk density, porosity and the roundness of the samples are correlated as the greater the bulk density and the lower the porosity of the samples. Porosity was remarkably varied by the degree of milling. The porosity of the tested rice varieties significantly differences at ($P>0.05$) confident interval.

Cooking and milling properties of rice varieties

Rice milling is one of the most vital operations in rice processing because it determines the economic value of rice grain. The numerous benefits of rice milling were to obtain an edible white rice kernel that will be enough for consumers and free from impurities (Singh *et al.*, 2005). Tanveer *et al.* (2016) reported that cooking time of rice grain is basically obtain when 90% of starch of the rice grain is no longer showing an opaque center (Dipti *et al.*, 2003).

Table 2. Cooking and Milling characteristics of rice varieties.

Properties	Illa	Abakaliki	Jemila	Ofada
Optimum cooking time (mins)	38	32	30	25
Water uptake ratio	6.12(1.34)	5.56(6.05)	5.84(0.911)	6.72(1.12)
Elongation ratio	1.34(0.94)	1.37(1.04)	1.51(1.12)	1.66(0.15)
Cooking length (mm)	5.5(2.13)	6.8(2.65)	4.28(4.05)	3.20(1.21)
Hulling percentage (%)	25.62(0.95)	18.42(0.76)	17.49(0.32)	13.25(0.53)
Broken percentage (%)	36.72(3.01)	28.78(2.05)	33.82(0.21)	36.67(0.95)
Swelling percentage (%)	62.79(4.05)	59.22(5.01)	56.86(1.23)	55.50(1.54)
Milling recovering (%)	15.71(2.04)	15.65(0.43)	14.16(3.05)	15.24(1.05)

Note: The values in brackets are standard deviations of the replicated mean values of the samples.

From Table 3, the amylose content of tested rice varieties which determine the gelatinization temperature, pasting behavior, viscoelastic parameters of rice samples were showed in Table 3. Furthermore, the amylose content of unprocessed rice varieties flour is an vital factor which determines the last use of numerous products such as noodles (Eke-Ejiofor and Nwiganale, 2016) and it also an important criteria in classifying rice systems (Merynda *et al.*, 2016). The amylose content for Illa, Abakaliki, Jemila and Ofada rice varieties were 23.73, 23.45, 24.42 and 25.64% respectively. Falade and Christopher (2015) reported low amylose content in rice samples provides softness, moistness, and chewiness to product textures. From the findings, it showed that Ofada rice had highest value (25.64%) of amylose content, followed by Jemila rice which recorded 24.42% of amylose content. The lowest value (23.45%) was found in Abakaliki rice followed by Illa rice sample with 23.73% amylose content. These findings of amylose content of the studied rice varieties were in line with the report of Eke-Ejiofor and Owuno (2012) on wheat flour. Amylose content of rice varieties was classified into four classes, very low (<10%), low (10-20%), moderately low (20-24%) and high (>25). it would produce no sticky rice, expand and became hard when it cold (Siyafutri *et al.*, 2016). Illa (23.73%), Abakaliki (23.45%) and Jemila (24.42%) with moderate amylose content had fluffier texture generally (Indrasari *et al.*, 2009). Based on this classification Ofada rice belongs to rice with high amylose content while other varieties belong to a rice moderate amylose content. From the findings, it was observed that amylose and starch content showed in different rice varieties maybe atributed to the application of fertilizer (nitrogen content), growing conditions, time and also location of the growing areas (Buresova *et al.*, 2010).

The amylopectin values of rice varieties studied were presented in Table 3. The amylopectin content of Illa rice, Abakaliki rice, Jemila rice and Ofada rice were 76.28%, 76.55%, 75.58% and 74.37% respectively. It was observed that Abakaliki rice sample had the highest value (76.55%) percentage of amylopectin and Ofada rice samples had the lowest value (74.37%) value of amylopectin. There is a slight significant variation among rice varieties tested at (P>0.05) in terms amylopectin content. From the report of Alaka *et al.,* (2011), it was revealed that amylopectin content of rice samples is a component of glucose molecules with a branched link and it has lower resistance to digestion. Rice sample with higher content of starch in form of amylopectin have the tendency of containing higher glycemic index (GI). Furthermore, food products with higher glycemic index (GI) can digest rapidly than those with lower GI values. Consequently, Ofada and Jemila rice are preferable due to their lower content of amylopectin and higher content of amylose which indicates relatively lower glycemic index (GI). Consequently, it be a perfect recommendation for a dieting diabetic patient (Frei and Becker, 2003; Alaka *et al.,* 2011).

The gelatinization temperature of studied rice varieties varied from 94.80°C for Illa rice, 84.78°C for Abakaliki rice, 83.13°C for Jemila rice and 82.38°C for Ofada rice sample. It influenced the water uptake and kernel elongation (Bhat and Riar, 2017). From the result presented in Table 3, it was observed that Illa rice had highest gelatinization temperature of 94.80°C whereas Ofada rice had lowest value (82.38°C) of gelatinization temperature. This finding is aligned with the report of Pokhrel *et al.* (2020) on cooking characteristics of rice varieties, practically, higher amylose content has less crystalline structure and has low gelatinization temperature, from this study Ofada rice sample had highest amylose content with lowest gelatinization temperature. Alaka *et al.* (2011) also stated that rice sample that contained high amylose content has moderate or low gelatinization temperature value although it was observed that rice with low or waxy amylose content reported to have higher or lower gelatinization temperature. Gelatinization temperature is solely dependent on the cooking time of the rice samples, according to Cuevas and Fitzgerald (2012) shorter cooking is mostly preferred as it save reasonable amount of energy and fuel.

The gelatinization time of the tested rice verities were presented in Table 3, the gelatinization time for Illa, Abakaliki, Jemila and Ofada rice were 6.77 mins, 5.70 mins, 5.56 mins and 5.70 mins respectively. It was observed that Illa rice had the highest value (6.77 mins) of gelatinization time while Abakaliki, Jemila and Ofada rice had similar values (5.70 mins, 5.56 mins and 5.70 mins) of gelatinization time. The changes in gelatinization time among the tested rice samples was attributed to varietal differences and independent of gelatinization temperature and cooking time. There was no significant difference at (P>0.05) among Abakaliki, Jemila and Ofada rice gelatinization time but Illa rice varied significantly at (P<0.05). This finding may be due to the type of starch contained in the tested rice samples (Alaka *et al.,* 2011).

From the result of chemical properties of cooked rice varieties presented in Table 3, the values for solubility index of tested rice samples were 10.69, 12.10, 9.54 and 10.01 for Illa, Abakaliki, Jemila and Ofada rice varieties. It was observed that Abakaliki rice had the highest value (12.10%) of solubility, followed by Illa rice which had 10.69% and Ofada rice had 10.01%. The lowest value (9.54%) was found in Jemila rice. These values of solubility index were varied more than the report of Eke-Ejiofor and Owuno (2012) on wheat flour and in range with the report of Eke-Ejiofor and Nwiganale (2016) on rice flour. The sample (Abakaliki rice) with higher solubility assosociated with the decreasing of its chain length of the starch molecules thereby decreasing the hydrogen bonds binding the granules together (Eke-Ejiofor and Nwiganale, 2016).

Water absorption capacity (WAC) is an important functional parameter that significally alters the gelatinization of starch contained in flour sample. Determining Water absorption capacity of processed flour is so important as it contribute immensely to development of new bio-products (Thomas *et al.*, 2014 and Bhat *et al.*, 2008). From the findings, it was observed that Illa rice had highest value (353.76%) of water absorption capacity this was attributed to the presence of hydrophobic amino acids which interferes with the ability of the rice starch to absorb water and increase in the amylose leaching and solubility and loss of starch crystalline structure, followed by Abakaliki rice with 185.76% WAC and Ofada rice which had 158.62% WAC. The lowest value (155.60%) of WAC was found in Jemila rice variety. The Illa rice variety varied significantly among other varieties at (P>0.05) confidence interval. This result was similar with the report of Racheal *et al.* (2014) on the reported functional and pasting properties of Nigerian local and imported rice varieties form Malaysia rice. The variation in the water content of the rice samples were associated with the presence of hydrophobic amino acids which interferes with the ability of the rice starch to absorb water (Ajatta *et al.*, 2016; Singh *et al.*, 2005). This result was associated with the loose amylose and amylopectin in the native starch granules and the weak binding force (Williams *et al.*, 2002 and Ihegwuagu *et al.*, 2009).

CONCLUSION

The four rice varieties grown in different region in Nigeria were evaluated for physical, cooking, milling and chemical characteristics. The result from axial dimension classified all the studied rice varieties as long grains. Illa rice recorded highest value (43.96 g) of 1000 grain weight while lowest value of 20.46 g was observed in Ofada rice. All the tested samples displayed good Milling behavior. Ofada rice elongated more than other varieties. The broken percentage was higher and lower in Illa rice (36.72%) and Abakaliki (28.78%) respectively. There are similarities in milling recovering of rice varieties but Illa had highest expansion (swelling) capacity while Ofada had lowest swelling power. Amylose and gelatinization temperature showed a good relationship, Ofada rice with higher amylose content had lowest gelatinization temperature. The cooking time of the rice sample varied from 5.56 min to 6.77 mins, Jemila rice will cook fast than other varieties. Illa rice had highest value (353.76%) of water absorption capacity, followed by Abakaliki rice with 185.76% WAC and Ofada rice which had 158.62% WAC. The lowest value (155.60%) of WAC was found in Jemila rice variety.

DECLARATION OF COMPETING INTEREST

The authors declareted that there is no conflict of interest during and afater this research.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Authors declare the contributions to the manuscript such as the following sections:
Patrick Ejike Ide: Investigation, formal analysis, writing - original draft, methodology, writing - original draft.
Omenogor Ikoko: Investigation, writing - original draft, data curation.
Helen Onyeaka: Methodology, validation and review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1200654

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 370-379

Research Article
(Araştırma Makalesi)

Eggplant (*Solanum melongena* L.) Drying Kinetics and Color Change

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ABSTRACT

Eggplant is used intensively in addition to its fresh consumption, as well as dried. With the drying process, it can be stored for a longer time and can be consumed in four seasons. In this study, the color criteria and drying kinetics, which are important quality parameters, were determined by drying the eggplant oven in a laboratory type convective dryer at 40, 50, 60, 70°C and in the shade environment. Before the drying process, the products were sliced in equal thickness and dried in a thin layer drying model and color measurements were made. When the drying datas were examined, the longest drying time was 124 hours in the shade environment, the shortest drying process was 3 hours 45 minutes in the laboratory type convective dryer at 70°C. Page, Midilli-Küçük, Lewis and Jena & Das models were used for drying modeling. The reliability level in modeling was found to be $p<0.001$ for all models. The highest R^2 value was found to be 0.9998 in the drying models, at 40°C in the laboratory type convective dryer in the Page model, and at 60°C in the laboratory type convective dryer in the Midilli-Küçük model. The chroma value, which is closest to fresh in color properties calculated in terms of color values, was found at 60°C in the oven dryer, the hue angle at 60°C in the laboratory type convective dryer, and the total color change and browning index at 70°C in the laboratory type convective dryer.

RESEARCH ARTICLE

Received: 08.11.2022
Accepted: 05.12.2022

Keywords:

- Eggplant,
- Drying,
- Color change,
- Mathematical modelling

To cite: Gök H, Olgaç M and Polatcı H (2022). Eggplant (*Solanum melongena* L.) Drying Kinetics and Color Change. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 370-379.* https://doi.org/10.46592/turkager.1200654

Patlıcan (*Solanum melongena* L.) Kuruma Kinetiği ve Renk Değişimi

ÖZET

Patlıcan taze tüketiminin yanı sıra kurutularak da yoğun bir şekilde kullanılmaktadır. Kurutma işlemi ile daha uzun süre muhafaza edilerek dört mevsim tüketim imkânı sağlanabilmektedir. Bu çalışmada patlıcan etüvde, laboratuvar tipi konvektif kurutucuda (LTKK) 40, 50, 60, 70°C sıcaklıklarda ve gölgede kurutularak önemli kalite parametrelerinden olan renk kriterleri ve kuruma kinetiği belirlenmiştir. Kurutma işlemi öncesi ürünler eşit boyutlarda dilimlenerek ince tabaka kurutma modelinde kurutularak renk ölçümleri yapılmıştır. Kurutma verileri incelendiğinde en uzun kuruma süresi 124 saat süren gölgede kurutmayken en kısa süren kurutma işlemi 3 saat 45 dakika LTKK 70°C sıcaklıkta bulunmuştur. Kurutma modellemesinde Page, Midilli-Küçük, Lewis ve Jena & Das modelleri kullanılmıştır. Modellemede güvenilirlik seviyesi tüm modeller için $p<0.001$ olarak bulunmuştur. Kurutma modellerinde en yüksek R^2 değeri 0.9998 olarak Page modelinde LTKK 40°C sıcaklıkta, Midilli-Küçük modelinde ise LTKK 60°C sıcaklıkta tespit edilmiştir. Renk değerleri açısından hesaplanan renk özelliklerinde tazeye en yakın olan kroma değeri etüv kurutucuda 60°C sıcaklıkta, hue açısı LTKK 60°C sıcaklıkta, toplam renk değişimi ve kahverengileşme indeksi ise LTKK 70°C sıcaklıkta bulunmuştur.

ARAŞTIRMA MAKALESİ

Alınış tarihi: 08.11.2022
Kabul tarihi: 05.12.2022

Anahtar Kelimeler:

- Patlıcan,
- Kurutma,
- Renk değişimi,
- Matematiksel modelleme

Alıntı için: Gök H, Olgaç M ve Polatcı H (2022). Patlıcan (*Solanum melongena* L.) Kuruma Kinetiği ve Renk Değişimi. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 370-379*. https://doi.org/10.46592/turkager.1200654

GİRİŞ

Patlıcan (*Solanum melongena* L.) Solanaceae familyasından önemli bir sebzedir. İlk yetiştiriciliği ise Hindistan'da yapılmıştır. Ülkemizde çok sayıda meyve ve sebze çeşidinin üretimi yapılmaktadır. Bunlardan biri olan patlıcan insan beslenmesinde önemli bir yer tutmaktadır. Ayrıca ülkemiz patlıcan üretiminde dünyada önde gelen ülkeler arasındadır (Akkuş, 2015). FAO (2022) verilerine göre, Çin 36.593.224 ton ile ilk sırada, Hindistan 12.777.000 ton ile ikinci sırada, Mısır 1.341.312 ton ile üçüncü sırada yer alırken Türkiye 835.422 ton ile dördüncü sırada yer almaktadır.

Birçok ülkede çeşitli meyve ve sebze üretimi yapılmaktadır. Fakat kısıtlı işletme imkanlarından kaynaklı uzun süre muhafaza edilemeyen ürünler kısa sürede bozularak israf olmaktadır (Karim ve Hawlader, 2005). Bu durumu engellemek için tarımsal ürünlerin bir şekilde muhafaza edilmeleri gerekmektedir. Konserveleme, dondurma ve kurutma işlemleri raf ömrünü uzatmak için kullanılan muhafaza yöntemleridir (Kaya ve Aydın, 2008). Kurutma işlemi birçok sektörde yaygın olarak kullanılmaktadır. Özellikle gıda sektöründeki kullanımı ürünlerin uzun süre saklanabilmesine, boyut ve ağırlıklarının azalmasıyla beraber taşıma maliyetlerinin düşmesine ve daha yoğun besin değerine sahip son ürünlerin elde edilmesine imkân sağlamaktadır.

Tarımsal ürünlerin kurutulması için birçok yöntem uygulanabilmektedir. Bu yöntemlerin başında açıkta kurutma işlemi yer almaktadır. Bu yöntemde yapılan kurutma işlemlerine göre enerji tüketimi olmaması açısından çok ekonomik bir metottur. Ancak ürünler homojen bir şekilde kurumamakta ve son ürünlerde önemli hijyen sorunlarıyla karşılaşılmaktadır. Vakum, etüv, mikrodalga, infrared vb. kurutucularda ise hızlı bir şekilde kuru ürün temini sağlanabilmekte ve son kalite özellikleri daha iyi kuru ürünler elde edilebilmektedir.

Bu çalışmada patlıcan, etüv ve laboratuvar tipi konvektif kurutucuda (LTKK) farklı kurutma havası sıcaklığında (40, 50, 60 ve 70°C) ve gölgede kurutularak renk ve kuruma kinetiği açısından karşılaştırılarak en iyi kurutma yönteminin ve sıcaklığının belirlenmesi amaçlanmıştır.

MATERYAL ve YÖNTEM

Kurutma materyali

Kurutma işlemine tabii tutulan patlıcan Tokat merkezde bulunan yerel marketlerden temin edilmiştir. Ürünün yeni hasat edilmiş olmasına özen gösterilmiştir. Kullanılan ürün laboratuvar ortamında +4°C sıcaklıktaki buzdolabında muhafaza edilmiştir.

Nem tayini

Taze patlıcan sebzesinin nem içeriğinin belirlenmesi için ürünler eşit boylarda dilimlenerek 70°C sıcaklıktaki etüvde son ağırlık değeri sabitlenene kadar kurutulmuştur (Yağcıoğlu, 1999).

Kurutma yöntemi

Ürünler kurutma işlemi öncesinde eşit boyutlarda dilimlenmiş hazırlanan ürünler ise laboratuvar tipi konvektif kurutucuda (LTKK), etüvde ve gölgede kurutulmuştur. Çalışma sırasında kurutma sıcaklığının sabitlenmesi için kurutucular yarım saat önceden çalıştırılmıştır. Kurutma işlemi için kullanılan örnek miktarları etüv için 100±5 g, laboratuvar tipi konvektif kurutucu için 140±5 g ve gölgede yapılan kurutma işleminde ise 100±5 g olarak kullanılmıştır. Kuruma sırasında ağırlık değişimlerinin belirlenmesi için belirli aralıklarla tartım yapılmıştır. Başlangıçta 30 dakika ile başlanmış sonra 60, 120 ve 180 dakika aralıklarla ölçüm alınmaya devam edilmiştir.

Patlıcanın en uygun kurutma sıcaklığının belirlenmesi için etüvde ve laboratuvar tipi konvektif kurutucuda 40, 50, 60 ve 70°C sıcaklıklarda ve gölgede kurutulmuştur. Kurutucularda ve gölgede işleme tabi tutulan ürünlerin nem içeriği %10-13 nem değerine düşene kadar kurutulmuştur. Yapılan tüm denemeler üç kez tekrar edilmiştir.

Denemede kullanılan kurutucular

Çalışma kapsamında kullanılan etüv, Şimşek Laborteknik marka olup ST-120 modelidir. Kabin sıcaklığı etüv içeriğinde bulunan sensörler ile ölçülerek kontrol ünitesine iletilmektedir. Kurutma havası sıcaklığı etüv üzerinde bulunan kontrol ünitesi üzerinden ayarlanmaktadır.

Kullanılan laboratuvar tipi konvektif kurutucuda (LTKK) ise kurutma odası üç adet kurutma kanalı ve kontrol panosundan oluşmaktadır. Isıtılan hava kanallar aracılığı ile ürünlere iletilmektedir. Kullanılan kurutucular Şekil 1' de verilmiştir.

a)

b)

c)

Şekil 1. Kurutma yöntemleri. a) Etüv Kurutucu b) Laboratuvar tipi konvektif kurutucu c) Açık Ortamda Kurutma Düzeni.
Figure 1. *Drying methods. a) Oven Dryer b) Laboratory convective dryer c) Drying box*

Kuruma modelleri

Ürünlerden kuruma işlemleri süresince ayrılabilir nem oranı (ANO) değerleri verilen eşitlik aracılığıyla hesaplanmıştır Ayrılabilir nem oranını hesaplamak için Kılıç (2017), Darniadi ve ark. (2018), Pestaño ve ark. (2018) 1 nolu eşitliği kullanmışlardır.

$$\mathrm{ANO} = \frac{\mathrm{M}-\mathrm{M_e}}{\mathrm{M_0}-\mathrm{M_e}} \tag{1}$$

ANO: Ayrılabilir nem oranı
M: Anlık nem içeriği
M_e: Denge nemi
M_o: İlk nem içeriği

Kuruma eğrilerini oluşturmak için patlıcan ve benzeri ürünler için yoğun bir şekilde kullanılan Jena & Das, Lewis, Midilli-Küçük ve Page ince tabakalı kuruma modelleri uygulanmıştır. Anılan modellerin eşitlikleri Çizelge 1'de verilmiştir. Eşitliklere ait modeller SigmaPlot 10. Programı kullanılarak regresyon analizine tabi tutulmuştur.

Çizelge 1. Kuruma modeli eşitlikleri.
Table 1. *Drying model equations.*

Model ismi	Eşitlik	Kaynak
Jena & Das	MR= h.exp (-j.(t^k))+(m.t)	Jena ve Das (2007)
Lewis	MR= exp (-k.t)	Lewis (1921)
Midilli-Küçük	MR= h.exp(-j.(tk))+(m.t)	Alibaş (2012)
Page	MR= exp (-h.(t^j))	Page (1949)

MR: Modelin fonksiyonu, k-h-j-m: Modele ait sabit katsayılar, t: Süre

Renk analizi

Taze ve kurutulmuş patlıcan örneklerinin renk ölçümleri Konica Minolta marka, CR400 model (Japonya) renk ölçerle yapılmıştır. Cihazda *L, a, b* renk değerleri ölçülmüştür. *L*, ürünün parlaklık değerini ifade etmekte ve 0-100 arasında değişmektedir. Kırmızı-yeşil *a* değerini, sarı-mavi renkler ise b değeri ifade ederken sırasıyla (+, -) değerlerini almaktadır (McGuire, 1992). Ölçülen renk değerleri (*L, a, b*) kullanılarak; kroma *(C)*, hue°, renk değişimi (*ΔE*) ve kahverengileşme indeks *(BI)* değerleri de hesaplanmıştır. Hesaplanan renk kriterlerine ait eşitlikler Çizelge 2'de verilmiştir.

Çizelge 2. Hesaplanan renk kriterlerine ait eşitlikler.
Table 2. *Equations for the calculated color criteria.*

Renk değeri	Eşitlik	Kaynak
Kroma, *C*	$C = (a^2 + b^2)^{1/2}$	Si ve ark. (2016)
Hue, °	$h^\circ = \tan^{-1}(\frac{b}{a})$	McGuire (1992)
Renk değişimi, *ΔE*	$\Delta E = \sqrt{(L - L*)^2 + (\boldsymbol{a} - \boldsymbol{a}*)^2 + (b - b*)^2}$	Dak ve ark. (2014)
Kahverengileşme İndeksi	$\mathrm{BI} = \frac{[100(x=0,31)]}{0,17}$, $x = \frac{a + (1.75xL)}{[(5.645xL) + (a = (3.012xb))]}$	Plou ve ark. (1999)

İstatistiksel analiz

Kurutma sıcaklıklarının patlıcanın renk değerlerine olan etkisinin istatistiksel açıdan önemini belirlemek için SPSS paket programında $p<0.05$ önem seviyesine göre, çoklu karşılaştırma analizi (DUNCAN) yapılmıştır.

BULGULAR ve TARTIŞMA

Kuruma değerleri

Patlıcan sebzesinin ilk nem içeriği 6 tekrar olacak şekilde belirlenmiş ve ortalama %93.79 olarak bulunmuştur. Son nem içeriği %10-13 seviyesine gelene kadar kurutma işlemi yapılmıştır.

Çizelge 3. Kuruma performans değerleri.
Table 3. *Drying performance values.*

Kurutma yöntemi	Kurutma sıcaklığı	Ortalama son nem (%)	Kuruma süresi (dk.)
Etüv kurutucu	40°C	10.21	2220
	50°C	10.08	1170
	60°C	10.26	1020
	70°C	12.36	570
LTTK	40°C	9.90	735
	50°C	10.08	390
	60°C	11.51	345
	70°C	10.54	225
Gölgede kurutma	-	12.82	7440

Kuruma performans değerlerine (Çizelge 3) göre ürünün içeriğindeki mevcut nemin istenilen aralığa laboratuvar tipi konvektif kurutucuda 70°C sıcaklıkta 3 saat 45 dakikada ulaştığı ve kurutma yöntemleri arasında en kısa süren kurutma yöntemi olduğu belirlenmiştir. En uzun süren kurutma yöntemi ise 124 saatte istenilen nem içeriğine düşen gölgede kurutma olmuştur. Tüm kurutma yöntemlerinde sıcaklığın artışı kuruma süresini kısaltmıştır.

Kutlu ve İşci (2016), çalışmalarında farklı kurutma yöntemlerinin patlıcanın kuruma karakteristikleri üzerine etkisini araştırmış olup kurutma sıcaklığının artmasıyla kuruma süresinin azaldığını tespit etmiştir.

Doymaz ve Aktaş (2018), yaptıkları çalışmada patlıcan dilimlerinin kurutma ve rehidrasyon karakteristiklerini incelemişlerdir. Uyguladıkları ön işlemlerde (sitrik asit ve haşlama) ve kontrolde kurutma sıcaklığı arttıkça kurutma hızının arttığı ve bunun sonucu olarak da kurutma süresinin düştüğü gözlemlenmiştir.

Kuruma modellerine ait katsayılar, "R^2" değerleri

Matematiksel modellere ait R^2 değerlerine bakıldığında en yüksek değer 0.9998 ile laboratuvar tipi konvektif kurutucuda 40°C kurutma havasında Page modelinde ve laboratuvar tipi konvektif kurutucuda 60°C'de Midilli Küçük modelinde belirlenmiştir (Çizelge 4).

Çizelge 4. Matematiksel modellere ait R^2 değerleri.
Table 4. *R^2 Values of mathematical models.*

Model eşitlikleri	Kurutma yöntemi	Kurutma sıcaklıkları	R^2	p
Page	Etüv	40°C	0.9851	<0.0001
		50°C	0.9952	<0.0001
		60°C	0.9978	<0.0001
		70°C	0.9976	<0.0001
	LTTK	40°C	0.9998	<0.0001
		50°C	0.9986	<0.0001
		60°C	0.9997	<0.0001
		70°C	0.9991	<0.0001
	Gölge	-	0.9986	<0.0001
Midilli-Küçük	Etüv	40°C	0.9983	<0.0001
		50°C	0.9994	<0.0001
		60°C	0.9986	<0.0001
		70°C	0.9993	<0.0001
	LTTK	40°C	0.9997	<0.0001
		50°C	0.9992	<0.0001
		60°C	0.9998	<0.0001
		70°C	0.9997	<0.0001
	Gölge	40°C	0.9996	<0.0001
Lewis	Etüv	40°C	0.9391	<0.0001
		50°C	0.9705	<0.0001
		60°C	0.9853	<0.0001
		70°C	0.9648	<0.0001
	LTTK	40°C	0.9996	<0.0001
		50°C	0.9985	<0.0001
		60°C	0.9995	<0.0001
		70°C	0.9965	<0.0001
	Gölge	-	0.9770	<0.0001
Jena & Das	Etüv	40°C	0.9505	<0.0001
		50°C	0.9780	<0.0001
		60°C	0.9890	<0.0001
		70°C	0.9746	<0.0001
	LTTK	40°C	0.9997	<0.0001
		50°C	0.9986	<0.0001
		60°C	0.9996	<0.0001
		70°C	0.9968	<0.0001
	Gölge	-	0.9828	<0.0001

LTTK: Laboratuvar Tipi Konvektif Kurutucu

Renk değerleri

Taze ve kurutulmuş patlıcan sebzelerine ait ölçülen *L, a* ve *b* değerleri ile hesaplanan renk değerleri olan kroma, hue açısı, renk değişimi ve kahverengileşme indeksi değerleri Çizelge 5'te verilmiştir.

Çizelge 5. Ölçülen renk değerlerin ve hesaplanan değerlerin ortalama değerleri.
Table 5. *The average values of measured color values and calculated values.*

Yöntem	*L*	*a*	*b*	*C*	*H °*	*ΔE*	*BI*
Taze	76.96	-2.41	18.87	19.04	-82.75	-	-
Etüv 40°C	65.83	2.84	19.13	19.44	81.40	53.76	41.35
Etüv 50°C	72.33	1.91	17.04	18.82	69.46	116.43	33.96
Etüv 60°C	68.00	3.93	18.28	18.83	77.65	57.30	35.76
Etüv 70°C	69.86	4.52	17.25	17.87	75.01	54.53	32.93
LTTK 40°C	66.29	1.8	17.83	17.97	71.80	59.19	33.05
LTKK 50°C	72.33	1.91	17.04	17.17	71.75	59.18	28.86
LTKK 60°C	79.27	0.30	15.11	15.12	28.88	85.34	21.09
LTKK 70°C	69.31	2.27	16.38	16.57	70.12	64.23	28.92
Gölge	63.88	3.92	19.43	19.89	78.65	48.46	40.86

Çizelge 5'e göre, ortalama en yüksek parlaklık değerinin laboratuvar tipi konvektif kurutucuda 60°C sıcaklıkta olduğu gözlemlenirken en düşük parlaklık değerinin ise gölgede kurutma yönteminde belirlenmiştir. Doymaz ve Aktaş (2018), çalışmalarında patlıcanın kurutma işlemine tabi tutulduğunda polifenoloksidaz enzimi aktifleştiğinden kararmaların meydana geldiğini belirtmişlerdir.

Hesaplanan değerler incelendiğinde etüv kurutma yönteminde sıcaklığın artmasıyla kahverengileşme indeksinin düştüğü ancak kroma değerinin yükseldiği gözlemlenmektedir. Laboratuvar tipi konvektif kurutucuda ise sıcaklığın yükselmesi kroma ve kahverengileşme indeksi değerlerini düşürmüştür. Tüm parametreler göz önünde bulundurulduğunda patlıcanın kurutulmasında renk parametrelerine göre en iyi sonuç etüv kurutucu için 40°C Laboratuvar tipi konvektif kurutucu için ise 70°C olarak belirlenmiştir. Gölgede kurutma işleminde ise ürünün renk değerleri olumsuz yönde etkilenmektedir.

Çizelge 6. DUNCAN testinin sonuçları.
Table 6. *DUNCAN test results.*

Yöntem	*L*	*a*	*b*
Taze	76.96^{ab}	-2.41^{d}	18.87^{ab}
Etüv 40°C	65.83^{d}	2.84^{b}	19.13^{a}
Etüv 50°C	72.33^{bc}	1.91^{b}	17.04^{cd}
Etüv 60°C	68.00^{cd}	3.93^{a}	18.28^{abc}
Etüv 70°C	69.86^{cd}	4.52^{a}	17.25^{bcd}
LTKK 40°C	66.29^{d}	1.88^{b}	17.83^{abcd}
LTKK 50°C	72.33^{bc}	1.91^{b}	17.04^{cd}
LTKK 60°C	79.27^{a}	0.30^{c}	15.11^{e}
LTKK 70°C	69.31^{cd}	2.27^{b}	16.38^{de}
Gölge	63.88^{d}	3.92^{a}	19.43^{a}

Çizelge 6' ya göre *L, a* ve *b* değerleri taze ürün ile karşılaştırıldığında %5 önem seviyesinde istatistiki açıdan farklı bulunmuştur. Patlıcan için önemli renk parametresi olan L değeri incelendiğinde etüv 40°C, LTKK 40°C ve gölgede kurutma arasında, etüv 50°C ile LTKK 50°C arasında ve etüv 60°C, 70°C ve LTKK 70°C arasında istatistiksel fark bulunamamıştır.

SONUÇ

Türkiye'de farklı iklim ve toprak yapısından kaynaklı birçok tarımsal ürün yetiştiriciliği yapılmaktadır. Bu ürünlerden biri de patlıcandır. Patlıcanın insan sağlığındaki değeri göz ardı edilemeyecek seviyede olduğu bilinmektedir. Güçlü bir antioksidan kaynağı olan patlıcana her mevsim ulaşabilmek amacıyla bazı muhafaza çalışmaları yapılmaktadır. En çok bilinen ve tercih edilen muhafaza yöntemlerinden biri kurutmadır. Kurutma işlemlerinde kurutma sıcaklığının belirlenmesi çok önemlidir.

Yapılan bu çalışmada patlıcan etüvde, laboratuvar tipi konvektif kurutucuda (40, 50, 60 ve 70°C) ve gölgede kurutulmuştur. Kuruma parametreleri göz önünde bulundurulduğunda en uzun kuruma süresi 124 saat ile gölgede kurutmada, en kısa kuruma süresi ise 3 saat 45 dakika olarak laboratuvar tipi konvektif kurutucuda 70 °C sıcaklıkta belirlenmiştir. Kuruma süresinin sıcaklığın artmasıyla azaldığı belirlenmiştir. Kurumayı en iyi tahmin eden model ise Page ve Midilli-Küçük modelleridir. Patlıcan için en önemli renk kriteri olan kahverengileşme indeksi incelendiğinde en iyi sonuç laboratuvar tipi konvektif kurutucuda 60°C sıcaklıkta gözlemlenmiştir. Bütün parametreler göz önünde bulundurulduğunda laboratuvar tipi konvektif kurutucuda 70°C kurutma sıcaklığının etüv kurutucuda ise 40°C daha uygun olduğu belirlenmiştir.

Patlıcanın kalite parametreleri açısından önemli değeri olan kroma ve kahverengileşme indeksleri açısından 60°C kurutma sıcaklığı daha uygun bulunmuştur. Fakat kuruma süresinin daha önemli olduğu durumlarda 70°C kuruma sıcaklığının da kullanılabileceği önerilmektedir.

ÇIKAR ÇATIŞMASI

Yazarlar herhangi bir çıkar çatışması olmadığını beyan ederler.

YAZAR KATKISI

Yazarlar olarak makaleye aşağıdaki katkıların sunulduğunu beyan ederiz.
Hüsne Gök: Çalışmanın yazım aşamasında ve kurutma denemelerinin yapılmasında katkı sağlamıştır.
Mehmetcan Olgaç: Kuruma ve modelleme verilerinin işlenmesi aşamasında katkı sağlamıştır.
Hakan Polatcı: Çalışma materyalinin temininde, planlama, kontrol ve analiz aşamasında katkı sağlamıştır.

ETİK KURUL KARARI

Bu makale Etik Kurul Kararı gerektirmemektedir.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1116725

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 380-396

Review Article

Comparative Study of the Developed Peanut Shelling Machines

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ABSTRACT

The comparative study in the development of peanut shelling machines is presented. Peanut shelling constitutes a significant part of peanut processing. Researchers had developed different type of peanut shelling machines, addressing the problem of shelling groundnut. Some authors modified past machines to improve efficiency and get the best possible output. This study presents the trends of these shelling machines, performance evaluation, merits, and demerits. A look at the factors affecting the performance of the shelling operation is also considered. These factors include the groundnut size, moisture content, shelling speed, sieve, concave clearance. These factors were observed based on the operational parameters, including the shelling and cleaning efficiencies, mechanical damage, and throughput capacity. The operating speed of the machines ranged from 150-300 rpm; the range of the shelling efficiency, cleaning efficiency and terminal velocity were 78-98.32%, 50.63-91.67% and 7.7-12.9 m s^{-1} respectively, while the mechanical damage ranged between 5.3-17.4%; the variation in the performance evaluation parameters is caused by the moisture content, variety, concave clearance, shelling speed, shelling blades, type of concave sieve. It was revealed that as shelling speed increases, the mechanical damage and shelling efficiency increase whereas as the moisture content increases (5-15% wet base), the shelling efficiency decreases, and the mechanical damage and the terminal velocity increases respectively. These factors, in different ways, influence the revenue generated by farmers.

REVIEW ARTICLE

Received: 14.05.2022
Accepted: 01.07.2022

Keywords:

- Ground nut,
- Shelling machine,
- Shelling efficiency,
- Moisture content,
- Operational parameters,
- Performance evaluation

To cite: Adetola OA, Akinniyi OE and Olukunle EA (2022). Comparative Study of the Developed Peanut Shelling Machines. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 380-396.* https://doi.org/10.46592/turkager.1116725

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), also known as peanut or earthnut, is the most common crop for oil production in the world (Bhalavignesh *et al*., 2019). It is grown on about 19 million hectares of land across the earth, one-third landmass, and principally for its edible oil content and protein-rich seeds (Lawal *et al*., 2015). Groundnut is an important oil-related crop that is ranked the sixth in the universe. For humans, groundnut is a valuable source of edible oil (43-55%) and protein (25-28%) as well as feed for livestock (Darshan *et al*., 2018). Groundnut can be traced to the Latin American Brazilians (Ejiko *et al*., 2015). History shows that Peru was where groundnut was first cultivated (Karthik *et al*., 2018). West Africa is the leader in the production of peanuts among developing countries. Delhagen *et al*. (2003) identified 14 countries in West Africa involved in peanut production and estimated that growth has increased by over 53% in the last 25 years. This shows us the volume and interest of countries in groundnut trading and production.

Groundnut (peanut) has moved to be cultivated in over 100 countries globally (Ravindra *et al*., 2008), with developing countries contributing about 94% of the worldwide production (Ugwuoke *et al*., 2014). Groundnut is prevalent in Nigeria who is a significant producer of groundnut in Africa. In 2008, amongst countries such as the Gambia, Togo, and Ghana, Nigeria accounted for 51% of groundnut production in the West African region and 31% in Africa, making her the most prominent producer (Ajeigbe *et al*., 2015). This popularity can be seen in the different names given to it by various ethnic groups, such as *Epa* in southwestern Nigeria and *Isagua* in South-Eastern Nigeria. In northern Nigeria, we can see the groundnut pyramids far back as the 1950s to 1960s.

The use of groundnut cannot be overemphasized as it cuts across many industries. It ranges from consumptive usage to industrial usages. This is because of the nutritional values of groundnut, and it can serve as addictive for several industrial products. Before the groundnut is being processed for usages, it undergoes some pre-processes to ensure the best possible output. These include cleaning harvested groundnuts, removing dirt and plan debris, and drying groundnut to control the moisture content influence on processing. Some common uses of groundnut include groundnut oil and groundnut (peanut) butter.

Over the years, manual groundnut shelling has been the livelihood of many groundnut growers. This is commonly accomplished by matching groundnuts or beating a bag of groundnuts with sticks. This is a time-consuming and tedious operation. It is inefficient since it results in significant groundnut losses. Machines, on the other hand, are required for mechanical shelling but because of their size and cost, these machines are still not widely used. Impact action, stripping, rubbing, or a combination of these methods are used to remove kernels from groundnut pods. The most common method of shelling is to break the pods and release the kernel by pressing the groundnut between the index finger and thumb (Ugwuoke *et al*., 2014).

There are various methods of groundnut shelling, ranging from the traditional to the most recent ones. The methods of groundnut shelling are classified as follows by Ejiko *et al*. (2015). This is the manual application of energy by the groundnut shelling personnel. This includes the beating of groundnuts in bags, pressing the pods out with your hands, and manually operating a shelling machine by rotating the wheels with the hand. This method is time-consuming and is often inefficient.

From its nutritious content to its diverse applications, processed groundnut is necessary for human consumption. This necessitates making the best use of harvested groundnut, which is not always the case with traditional approaches. Traditional methods typically result in significant waste due to breakage while pounding, difficulties sorting and cleaning, and other factors. This results in lower earnings for groundnut farmers or owners, which may deter farmers from trading in groundnut. Also, because groundnut processing firms would want to break even by selling the products at prices that meet their budgets, this makes groundnut output expensive.

Only if a significant portion of the total groundnut shelled is converted for consumption in a fair amount of time will optimal utilisation be attainable. Many groundnut shelling machines developed by researchers and authors have solved this problem; some are reliable, have high shelling efficiency but are expensive, while others are less expensive but less efficient in shelling and cleaning (Kittichai, 1984; Gore *et al*., 1990; El-Sayed, 1999; Singh, 1993; Okegbile *et al*., 2014; Ugwuoke *et al*., 2014; Ejiko *et al*., 2015; Alonge *et al*., 2017; Muhammed and Isiaka *et al*., 2019; Madi, 2017; Bhalavignesh *et al*., 2019). This is the problem that this project will investigate, with the goal of developing a dependable and economical groundnut shelling machine. There are many groundnuts shelling machines all around the world. The development of a new groundnut shelling machine will necessitate the study of previous designs. If a better groundnut sheller is imagined, constructed, and developed, it will need to consider shelling efficiency, production costs, power consumption, maintenance costs, and so on. Engineers can use the data offered in this study to design better groundnut shelling machines by looking at the trends of the machines that have been built by researchers over time.

COMPARATIVE STUDY OF PEANUT SHELLING MACHINES

Comparative study of peanut shelling machines was carried out. This involved obtaining information from the developed peanut shelling machines from different researchers. The factors affecting the performance of the shelling operation were considered; mainly the crop factors and the machine-based variables. The crops factors considered include the moisture content and variety of the groundnut. The machine-based factors evaluated include concave clearance, shelling speed, shelling blades, and sieve size. The machine parameters reviewed include the shelling efficiency, cleaning efficiency, terminal velocity, mechanical damage, and throughput capacity. The contribution of the authors, merits, and demerits of the shelling machines were reviewed with the view to provide information for engineers to develop a better peanut shelling machine.

Factors affecting performance of groundnut shelling machines

Shelling efficiency, Mechanical damage, Material efficiency, Throughput capacity, Cleaning efficiency and Terminal velocity of a groundnut (peanut)

Groundnut shelling is a fundamental part of groundnut processing. Butts *et al.* (2009) estimated that groundnut shelling accounts up to 38 % of post-harvest costs. These large per cents give reasons for optimal performance for any groundnut shelling technique, in this case, machines. Groundnut shelling machines are influenced by three factors, according to Abubakar and Abdulkadir (2012). Crop factors and machine-based variables are the two factors covered here. The effect of these factors' characteristics on some observable dependent parameters is used to evaluate the performance of these machines. Shelling efficiency, cleaning efficiency, throughput, and mechanical damage are all common parameters. Darshan *et al.* (2018) recommends using equations 1 to 4 to estimate these parameters.

$$Shelling\ efficiency\ (\%) = \left(\frac{Q_s}{Q_t}\right) \times \frac{100}{1} \tag{1}$$

$$Mechanical\ damage\ (\%) = \left(\frac{Q_d}{Q_u+Q_d}\right) \times \frac{100}{1} \tag{2}$$

$$Material\ efficiency\ (\%) = \left(\frac{Q_u}{Q_u+Q_d}\right) \times \frac{100}{1} \tag{3}$$

$$Throughput\ capacity\ (\frac{kg}{h}) = \left(\frac{Q_s}{T_m}\right) \times \frac{100}{1} \tag{4}$$

Where Q_s is the total weight of shelled groundnut, Q_t is the total weight of groundnut, Q_d is the total weight of damaged groundnut, Q_u is the total weight of undamaged groundnut, and T_m is the time to shell the groundnuts.

Cleaning efficiency involves the separation of the dehulled seeds from the pod/chaff. Alonge *et al.* (2017) recommends using equation 5 to estimate the cleaning efficiency.

$$Cleaning\ efficiency\ (\%) = \frac{Wd}{W_{wp}}\ x\ \frac{100}{1} \tag{5}$$

Where W_d is the weight of dirt included in kernels and W_{wp} is weight of total dirt from shelled groundnut.

Terminal velocity is the greatest velocity that grains can achieve as they fall through air. It takes place when the downward force of gravity acting on the grains is equal to the drag force plus buoyancy (NASA, 2021).

$$V_t = \sqrt{\frac{2mg}{\rho A C_d}} \tag{6}$$

Where, V_t is the terminal velocity (m s^{-1}), m is the mass of falling grain (kg), g is the accelation due to gravity, ρ is the mass density of particle (kgs^2 m^{-4}), A is the Projected area of particle in perpendicular direction of motion (m^2), and C_d is the overall drag coefficient, g is the acceleration due to gravity (m s^{-2})

The terminal velocity for several types of pods

The terminal velocity for several types of pods varied from 7.7 to 12.9 m s^{-1}. Therefore, when creating devices for the separation of peanut parts, these variables could be taken into account. The air stream's velocity cannot be greater than 7.7 m s^{-1} in order to remove lighter material from the peanut pods (El-Sayed *et al.*, 2001). For peanuts, the terminal velocity increased from 7.25 to 7.93 m s^{-1} as the moisture content rose from 4.85 to 32.00 percent d.b. The terminal velocity was seen to rise linearly with increasing moisture content (Aydin, 2007). The findings are comparable to those made known by Kural and Carman (1997), however Aydin and Ozcan (2002) found that the values were lower than those for terebinth fruits. Due to the increased mass of a single peanut per unit frontal area exposed to the air stream, the terminal velocity increases as moisture content increases.

Crop factors

Mould growth, mite infestations, and sprouting can all be caused by excessively moist cereals and oilseeds, according to Armitage and Wontner-Smith (2008). On the other hand, over-drying grain before or during storage can cause splitting and cracking, as well as poor quality and energy waste. As a result, the moisture content is an important factor to consider (Rai *et al.*, 2005). For all groundnut cultivars investigated, Gitau *et al.* (2003) reported that shelling efficiency rose as moisture content dropped. This is in line with the findings of Atiku *et al.* (2004), who discovered that when moisture content rises, shelling efficiency falls, and seed damage rises. Gamal *et al.* (2009) discovered that raising the moisture content causes the axial dimensions of the kernel to increase. According to Nyaanga *et al.* (2007), shelling efficiency reduces as moisture content rises. This is because the pods become friable after being imparted, allowing them to bend rather than fracture. Only a fraction of the peanut is shelled as a result. Researchers such as Adedeji and Ajuebor (2002) proposed a moisture content of 10-15% wet base to achieve the optimum shelling results. Nyaanga *et al.* (2007) and Akcali *et al.* (2006) suggested 5% wet base and 13% wet base respectively. Gitau *et al.* (2003) later proposed a 5% wet base.

Variety

Shoko and Mushiri (2015) classified groundnut into four varieties: Runner, Virginia, Spanish, and Valencia, as presented in Figure 1. Each groundnut has its unique properties such as the number of kernels, colour, etc. Several researchers have investigated the physical properties of various groundnut cultivars. Gitau *et al.* (2003) conducted one of these investigations at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Kenya. Akcali *et al.* (2006) conducted another study on groundnut cultivars developed by the Turkish government. They calculated the size of groundnuts by taking the average of the axial measurements, which include the minor, intermediate, and major diameters of the kernel. Results from the study showed that there was higher shelling efficiency for larger varieties.

Figure 1. Varieties of groundnut (Shoko and Mushiri, 2015).

Machine based factors

Concave clearance

Shelling efficiency and mechanical damage rise as concave clearance decreases, according to researchers. Although many researchers agreed, their concave clearance numbers for the best result were different. In Thailand, clearance between 7 mm and 15 mm was used for different groundnut varieties local to Thailand. It was observed that less damage and decreased shelling efficiency were obtained with a larger clearance. This conclusion was similar to that of Nyaanga *et al.* (2007), who found that increasing the concave clearance from 20 mm to 30 mm boosted the machine's shelling efficiency from 73.6 percent to 79.8% and raising the clearance to 40 mm reduced it to 73.2 percent. Shelling efficiency declined as clearance increased, and damage decreased significantly as clearance grew from 8 to 12 mm and gradually as clearance rose from 12 to 20 mm, according to Rostami *et al.* (2009). Bobobee (2002) proposes a concave clearance of 16-18 mm when working on a variable speed motor running at 180-220 rpm.

Shelling speed

Shelling efficiency rose to a maximum with increased speed, but reduced with increased speed, according to Nyaanga *et al.* (2007). Rostami *et al.* (2009) came to the same conclusion, indicating that speed increased shelling efficiency but had no effect on peanut damage. When employing a variable speed motor, Bobobee (2002) discovered that speeds of 180-200 rpm generate an output range of 240-250 kg h^{-1} with a breakage rate of 10 – 14 percent in a pneumatic drum sheller. Further research into the ideal shelling speeds for castor oil fruits indicated that 240 rpm is the best. In their trials, Adedeji and Ajuebor (2002) and Balami *et al.* (2012) obtained the best groundnut shelling performance at 260 pm and 150 kg h^{-1} feed rate. In-field groundnut shelling tests were conducted by Butts *et al.* (2009) using a cylinder revolving between 160 and 300 pm.

Shelling blades

Gitau *et al.* (2003) discovered that steel rod blade shellers outperformed wooden blade shellers in terms of shelling efficiency. Groundnut pods are shelled when they pass between the shelling blades' space and the concave sieve. One of the factors that influence shelling performance is the material of the blade; others include the design of the blade and the number of blades. Helmy *et al.* (2007) found that the shelling efficiency of a rubber-covered drum was lower than that of a steel or hardwood drum in an experiment. At speeds of 1.83 m s^{-1} and 4.58 m s^{-1}, Helmy *et al.* (2007) discovered that increasing the number of blades from four to eight improved shelling efficiency. When rubbing peas, Kamboj *et al.* (2012) used L-shaped blades to generate maximal shelling motion. As a result, compared to shearing and impact, there was very little damage. Kernels with hard pods or coatings, such as Bambara nuts, are utilized in the shelling process, as are centrifugal impellers or rollers rotating in opposite directions (Siebenmorgan *et al.*, 2006).

Sieves

The sieve size for groundnut shelling machines is determined by the type of groundnut and, more specifically, the size of the groundnuts to be shelled. The slotted grate sieve and the wire mesh sieve are the two most frequent types of sieves. Helmy *et al.* (2007) found that the wire mesh sieve outperformed the slotted grate sieve in their study. Table 1 shows this information.

Table 1. Comparison of the wire mesh and slotted grate sieve.

Type of concave sieve	Shelling capacity (kg h^{-1})	Shelling efficiency (%)	Percentage breakage (%)
Wire mesh	86	83-89	3.7-6.7
Slotted grate	60	82-84	8.4-12.6

Source: Helmy *et al.*, 2007.

Trends in the development of groundnut shelling machines

The mechanized shelling machine is shown in Figure 1. This is the use of mechanical and electrically operated devices such as gasoline engines and electric motors. These devices are responsible for the operation of the machine as they supply the power required for shelling, either by converting mechanical energy from the gasoline engine or the electrical energy from the electric motor. This method consumes less time for shelling if compared to the manual methods considering the same tons of groundnut. Shelling mechanisms in the mechanized method involve reciprocating and rotary (Walke *et al.*, 2017).

Figure 2. Mechanized shelling (Walke *et al.*, 2017).

Over the years, there have been development of different groundnut shelling machines and decorticators by different group of engineers, intending to solve groundnut shelling-related problems. Kittachai (1984) developed the first recorded ground shelling machine which was called the power–operated groundnut sheller. This machine had a capacity of 210.5 kg h^{-1}. with it shelling efficiency and mechanical damage as 98% and 5.3% respectively. The machine capacity is lower than that of Muhammed and Isiaka *et al.* (2019) [233.81 kg h^{-1}], Ugwuoke *et al.* (2014) [400 kg h^{-1}] and Okegbile *et al.* (2014) [400 kg h^{-1}]. The shelling efficiency is higher than that of Okegbile *et al.* (2014) [78%], Gamal *et al.* (2009) [80%], Ejiko *et al.* (2015) [84%], Ugwuoke *et al.* (2014) [95.25] however it is similar to that of Muhammed and Isiaka *et al.* (2019) [98.32%]. The mechanical damage is lower than that of Ejiko *et al.* (2015) [14%], Okegbile *et al.* (2014) and Ugwuoke *et al.* (2014) [17.25%], Alonge *et al.* (2017) [17.4%] but higher than that of Muhammed and Isiaka *et al.* (2019) [4.33%]. The variation in the shelling efficiency and mechanical damage might be due to different concave clearance used by the various researchers because it has been reported by researchers that decrease in concave clearance led to increase in shelling efficiency and mechanical damage.

The machine served as the reference point for many other groundnut shelling machines developed afterwards. New machines are being developed globally and locally for improvement in shelling machines; shelling efficiency and mechanical damage for the best possible output.

Atiku *et al.* (2004) produced a Bambara groundnut sheller that operates by a rotational mechanism. Figure 3 shows a typical groundnut shelling machine in action. They considered how the moisture content of the groundnut affected the pace of shelling. They discovered that as the moisture level in the air rises, the efficiency of shelling diminishes.

Figure 3. Groundnut sheller by Atiku *et al.* (2004).

Raghtate and Handa (2014) performed and extensive research on the output of the shelling machine they developed. During first testing, they recorded a shelling capacity of 81.2% and mechanical damage of 20.03%. The shelling efficiency and mechanical damage obtained in this experiment is similar to the ones obtained by Okegbile *et al.* (2014) and Alonge *et al.* (2017). During their research, they decided to adjust the parameters such as feed rate, shelling speed, fan speed and used different moisture content. This led to different results as they recorded a shelling efficiency as high as 98.86% and cleaning efficiency as high as 99.17%. The variation in the value of cleaning obtained by different researchers might be due to the variation of the terminal velocity used by various authors because the terminal velocity plays a significant in the cleaning efficiency of a shelling machine. The shelling and cleaning efficiencies are in accordance with the ones reported by Ugwuoke *et al.* (2014). In another case, they recorded a mechanical damage as low as 1.1%. They tested the machine (Figure 4) on roasted groundnut and recorded a shelling efficiency of 66%. Their experiment revealed that the output of a machine can be improved by varying some parameters.

Figure 4. Groundnut sheller by Raghtate and Handa (2014).

Madi (2017) developed a prototype groundnut shelling machine to carry out evaluation at varying parameters of shelling speed, feed rate, and blower speed. The machine has a rubber shelling drum with a rough surface for shelling which was different from many other groundnut shellers having metallic shelling drums. When performing the evaluation, the shelling speed and blower speed ranged from 150 – 300 rpm and 4.9 – 8.8 m s^{-1}, respectively, with a feed rate of 170 kg h^{-1}, 210 kg h^{-1}, and 250 kg h^{-1}. The machine's output revealed that when the shelling speed increases, cleaning efficiency diminishes but shelling efficiency rises. This machine, shown in Figure 5, has a cleaning efficiency ranging between 94.8% to 98% for shelling speeds of 300 rpm and 150 rpm, respectively. Helmy *et al.* (2007) found that the wire mesh sieve outperformed the slotted grate sieve in their study. Ugwuoke *et al.* (2014) reported similar result but higher than that of Gamal *et al.* (2009) and Muhammed and Isiaka *et al.* (2019).

Figure 5. Prototype Groundnut sheller by Madi (2017).

Hoque and Hossain (2018) designed a power groundnut sheller, as presented in Figure 6. The shelling capacities of the groundnut sheller were 110 and 115 kg h^{-1} for two varieties of groundnut used, namely, Dhaka-1 and BARI Badam-8. The machine capacity is lower than that of Muhammed and Isiaka *et al.* (2019) [233.81 kg h^{-1}], Ugwuoke *et al.* (2014) [400 kg h^{-1}.] and Okegbile *et al.* (2014) [400 kg h^{-1}.].

Figure 6. Groundnut sheller by Hoque and Hossain (2018).

The shelling efficiency on the former and latter were 86.6% and 88.82%, respectively, at 11.5% moisture content wet base (wb). This is in accordance with the value obtained by Ejiko *et al.* (2015) and higher than that of Okegbile *et al.* (2014) [78%], Gamal *et al.* (2009) [80%], but lower than that of the values obtained by Ugwuoke et al. (2014) [95.25] and Muhammed and Isiaka *et al.* (2019) [98.32%]. Gitau *et al.* (2003) reported that factors such as material of the blade, the design of the blade and the number of blades influence the shelling performance of a peanut shelling machine. The kernel damage was 2% to 7.5% moisture content wet base (wb). According to the authors, using this machine can reduce shelling costs by 76% compared with manual methods. Based on their recommendation, the power groundnut sheller should be used at the farm and small industry levels.

Another of these machines was Darshan *et al.* (2018), which developed a low-cost groundnut shelling machine with a blower separation technique, as shown in Figure 7. They aimed to design and fabricate an affordable and portable that will shell as much groundnut as possible in the shortest possible time. Their performance evaluation of the shelling machine revealed its shelling efficiency as 95%, the mechanical damage is 0.088%, throughput capacity is 22.98 kg h^{-1}, and material efficiency of 91.15%. These results were obtained after five tests were carried out on the machine, with the average results considered. The shelling efficiency is in accordance with the values obtained by Ugwuoke *et al.* (2014) [95.25] and Muhammed and Isiaka *et al.* (2019) [98.32%] and higher than that of Ejiko *et al.* (2015) [84%], Okegbile *et al.* (2014) [78%] and *Gamal et al.* (2009) [80%]. Akcali *et al.* (2006) reported that larger varieties of peanut gave a higher shelling efficiency. Therefore, variation in the shelling efficiency reported by various researchers might be due to different varieties of peanut used in performing evaluation for their developed shelling machines. The mechanical damage is lower than of the values obtained by Ejiko *et al.* (2015) [14%], Okegbile *et al.* (2014) and Ugwuoke *et al.* (2014) [17.25%], Alonge *et al.* (2017) [17.4%] but higher than that of Muhammed and Isiaka *et al.* (2019) [4.33%]. The throughput capacity is lower than that of Muhammed and Isiaka *et al.* (2019) [233.81 kg h^{-1}], Ugwuoke *et al.* (2014) [400 kg h^{-1}.] and Okegbile *et al.* (2014) [400 kg h^{-1}.].

Figure 7. Groundnut sheller by Darshan *et al.* (2018).

Some contributions to the development of groundnut sheller by Nigerian researchers are presented in Tables 2 and 3. Global contributions are presented in Table 4.

Table 2. Nigerian contributions on groundnut shelling machine.

S/N	Names of authors on groundnut sheller	The contribution was made to the improvement of the groundnut shelling machine.
1	Darshan *et al.* (2018)	Performance evaluation of motorized groundnut sheller.
2	Atiku *et al.* (2004)	Performance evaluation of Bambara groundnut sheller
3	Maduako *et al.* (2006)	Testing of an engine-powered groundnut shelling machine
4	Oluwole *et al.* (2007)	Development and performance evaluation of impact Bambara groundnut sheller
5	Abubakar and Abdulkadir (2012)	Design and evaluation of a motorized and manually operated groundnut shelling machine
6	Ossom *et al.* (2020)	Modification and performance testing of a Bambara groundnut sheller
7	Alonge *et al.* (2017)	Design modification and performance testing of a Bambara groundnut sheller

Table 3. Output of some groundnut shelling machines developed by Nigerian researchers.

S/N	Names of authors	Power Output (hp)	Shelling capacity	Shelling efficiency (%)	Mechanical damage (%)	Cleaning efficiency (%)
1	Gamal *et al.* (2009)			80		79.5
2	Okegbile *et al.* (2014)	1	400 kg h^{-1}.	78	17.25	
3	Ugwuoke *et al.* (2014)	1	400 kg h^{-1}.	95.25	17.25	91.67
4	Alonge *et al.* (2017)		75000 seeds h^{-1}.	83.2	17.4	
5	Ejiko *et al.* (2015)	1		84	14	
6	Muhammed and Isiaka *et al.* (2019)		233.81 kg h^{-1}.	98.32	4.33	50.63

Table 4. Global contributions on groundnut shelling machine.

S/N	Names of authors	The contribution made on the improvement of the groundnut shelling machine
1	Kittichai (1984)	Development and test of a power-operated groundnut
2	Gore *et al.* (1990)	Development of power-operated groundnut sheller.
3	El-Sayed (1999)	A simple prototype of conical sheller
4	Singh (1993)	Development of a unique groundnut decorticator
5	Abou El-kheir and Shoukr (1993)	Modelling of the action of mechanical shelling of peanut for different materials of beater drum.
6	Younis and Abdel-Mawla (1997)	Development of peanut sheller.
7	Anantachar *et al.* (1997)	Development and performance evaluation of pedal operated decorticator
8	Helmy (2001)	Evaluation of a reciprocating peanut sheller
9	Nyaanga *et al.* (2003)	Development and evaluation of a portable hand operated groundnut sheller
10	Nyaanga *et al.* (2007)	Development and testing of a portable hand-operated groundnut sheller.
12	Rostami *et al.* (2009)	Design, development and evaluation of a groundnut sheller
13	Hoque *et al.* (2011)	Design and development of manual groundnut sheller
14	Gitau *et al.* (2003)	Optimizing the performance of a manually operated groundnut (Arachis hypogaea) decorticator
15	Helmy *et al.* (2013)	Modification and evaluation of a reciprocating machine for shelling peanut
16	Raghtate and Handa (2014)	Design and fabrication of groundnut sheller machine
17	Arjun *et al.* (2015)	Design and fabrication of groundnut decorticator
18	Wangette *et al.* (2015)	Influence of groundnut and machine characteristics on motorized sheller performance.
19	Mungase *et al.* (2015)	Peanut sheller using screw conveyor
20	Walke *et al.* (2015)	Design and fabrication of groundnut sheller machine
21	Madi (2017)	Manufacture and evaluation of a simple prototype of peanut sheller.
22	Bhalavignesh *et al.* (2019)	Modelling and fabrication of groundnut separating machine

The data obtained from the research revealed the following merits and demerits of some machines developed by Nigerians is presented in Table 5.

Table 5. Merits and demerits of some groundnut shelling machines developed by Nigerians.

S/N	Name of authors	Merit(s)	Demerit(s)
1	Okegbile *et al.* (2014)	Moderate shelling efficiency and shelling capacity	Do not have a cleaning compartment and high damage of kernel.
2	Alonge *et al.* (2017)	Moderate shelling efficiency and shelling capacity	High damage of kernel.
3	Muhammed and Isiaka *et al.* (2019)	High shelling efficiency and low damages caused to kernel	Cleaning efficiency is low, machine is not compact.
4	Ugwuoke *et al.* (2014)	High shelling efficiency and High cleaning efficiency	High damage of kernel
5	Ejiko *et al.* (2015)	Moderate shelling efficiency	Cleaning is done manually and high damage of kernel

CONCLUSION

The trends in the development of groundnut shellers had been presented. It was observed that these groundnut shelling machines improved on the previous ones developed in term of shelling efficiency, mechanical damage, cleaning efficiency, etc. This shows that for any machine to be developed, there is a need to observe the trends of the existing machine used for the same purpose. This will help the engineer understand what problem needs to be solved and what improvement needs to be made. Based on the review carried out, the following conclusions are made:

i. Groundnut shelling machines have been in development for over 35 years with drastic improvement occurring in each decade.
ii. The shelling of groundnut is affected by factors such as variety of groundnut, size of groundnut, moisture content, shelling techniques, shelling speed, etc.
iii. The power requirement for most machines observed is 1 hp. This was effective in operating the shelling machine.
iv. The cleaning efficiency of many of the machines for bought–out components such as blower was more effective than the locally developed ones.
v. Most machines used bought–out component (blower) compared to the locally developed fans for the cleaning compartments.
vi. Most of the shelling machines used metal for the shelling drum.

RECOMMENDATIONS

The goal of groundnut shelling machines at inception was not only to shell groundnut in a considerable period, but also to maintain optimum productivity. This will require researchers and engineers to take into consideration several factors that can improve or decline the productivity of the shelling machines during design and development process. The following under–listed are recommendations for future research and development:

1. There should be a universal model for measuring the performance evaluation of the machine. This will help engineers and researchers in identifying areas that need improvements.

2. The physical properties of the groundnut such as moisture content should be taken into considerations during the machine designs as it directly affects the machine efficiency.
3. Researchers should include specification such as the type or variety of groundnut that was used for experiment for easy comparison of machine outputs.
4. The use of other materials such as rubber for shelling drum is encouraged in further research. This will help in monitoring power consumption, shelling efficiency and mechanical damage.
5. Other means of power generation such as solar power is encouraged in future designs to help develop self–propelling shelling machines that can serve in remote area lacking access to electricity and fuel.
6. Research into automated groundnut shelling machines will make the process more effective with little or no human supervision.
7. Further research for the use of the groundnut chaffs can be instituted, thereby establishing sustainability and consequently promote circular economy in the country.

DECLARATION OF COMPETING INTEREST

The authors state that no conflict of interest exists.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

This review was carried out among all the three authors in collaboration. The research was planned by the three authors Olufemi Adeyemi Adetola, Opeyemi Emmanuel Akinniyi, and Emmanuel Ayodeji Olukunle.

Olufemi Adeyemi Adetola wrote the protocol and managed the searches for literature. Read, corrected the first draft of the manuscript, read and accepted the final manuscript.
Opeyemi Emmanuel Akinniyi supervised the study's analyses, managed the searches for literature, read and accepted the final manuscript.
Opeyemi Emmanuel Akinniyi wrote the first draft of the manuscript, read and accepted the final manuscript.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1060019

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 397-429

Review Article

Review on Solar Drying in Nigeria

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ABSTRACT

Nigeria, as one of the countries in the African continent has its challenges regarding to agricultural crops cultivation and its preservation methods. Traditional methods of preserving crops are commonly adopted by the local populace over solar dryer appliances. The reason for these includes being cheaper method, does not require much technical know-how, is easily learnable, the area for drying the agricultural crop produce being unlimited etc as when compared to solar dryers that needs materials to be fabricated, required little or medium knowledge of technical know-how, financial requirement for its fabrication which could range from few dollars to thousands of dollars. Solar dryer working principles, components, various classifications, and its mode of air movement and mode of heat transfer were discussed on this article. The article also reviewed some of the experimental researches on solar drying in Nigeria carried out by various scholars. The review of the published works on solar drying of various crops under different drying techniques were carefully studied. The results showed that, significant works on solar drying in Nigeria have been carried out even though its potential is greatly under-utilized due to various factors militating against it.

REVIEW ARTICLE

Received: 12.04.2022
Accepted: 28.06.2022

Keywords:

- Solar dryers,
- Agricultural crops,
- Drying

To cite: Okonkwo HO and Ertekin C (2022). Review on Solar Drying in Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 397-429.* https://doi.org/10.46592/turkager.1060019

INTRODUCTION

Nigeria, which was once a British colony got her independence in 1960. It was mostly under military rule until 1998 allowing the transition from military rule to civilian ruling. According to Anonymous (2019), Nigeria shares border with Gulf of Guinea, found between Benin and Cameroon. It is the most populous black country in the

African continent with a population of around 198 million (Anonymous, 2018) with a projection to double by 2050.

As a big country with various ethnic groups, more than 500 indigenous languages and multifaceted religions, it is situated at a location that helped her to have excellent weather condition. These weather conditions added to her rich arable lands encourages agriculture. Some of the popular agricultural crops cultivated and produced in Nigeria are cocoas, palm oil, corn, rice, sorghum, millet, maize, cowpea, soya beans, onions, okra, pepper, cassava (manioc tapioca), yams, rubber, cattle, timbers, etc. (Anonymous, 2022)

Unfortunately, as the weather conditions encourages agricultural cultivation, it also lead to loss of agricultural produces, mostly vegetables and fruits due to inadequate preservation methods. Generally, the preservation of agricultural produce is an ancient practice (Mulet *et al.*, 1993). Agricultural produces were dried in the open under the sun to preserve it. The importance of this practice was reduced because of the climatic adversities which leads to high product losses and the requirements of a lot of manpower during the drying process. To manage these problems related to open air sun drying such as low efficiency, agricultural product loss and deterioration, solar dryers were introduced (Romano *et al.*, 2009).

Solar drying

A solar dryer as an appliance helps transmit the heat from heat source to a product and at the same time transfer moisture found in the agricultural crops from the surface to the surrounding air (Chauhan *et al.*, 2015). The basic function of any given solar dryer is to increase the vapor pressure of moisture found inside the crop produce and increase the moisture carrying capacity of the drying air by decreasing its relative humidity (Sangamithra, 2014). During the solar drying process, the warm air captures moisture from the dried agricultural products. According to Elhage *et al.* (2018), the total quantity of moisture removed depends on the temperature of the dried air found in the environment. Figure 1 explains in general, the principle of solar dryer.

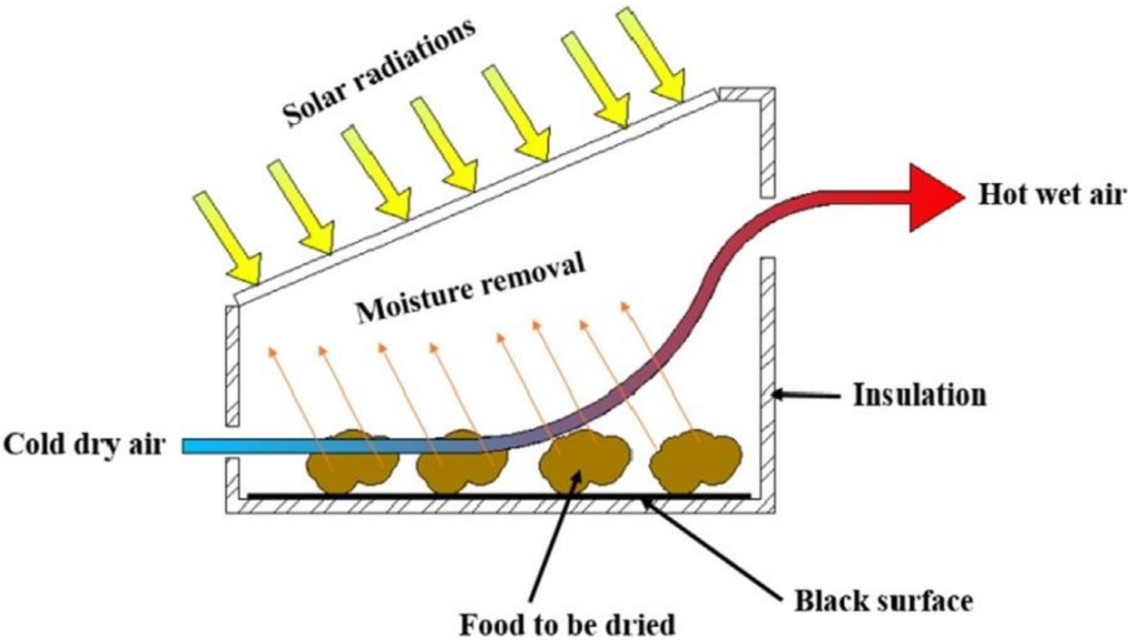


Figure 1. Schematic of principle of solar dryer (Elhage *et al.*, 2018).

Different components of Solar Dryers

As generally known, solar dryers are made up of three different components which include the drying chamber, air heater and air flow system. The location where the agricultural crops to be dried are placed is known as the drying chamber, which most times are covered leading to the protection of the agricultural products from dust and dirt. That chamber is mostly insulated, which helps in the increase the drying efficiency. The solar collector is a box with a transparent cover, while the remaining part is painted dark to prevent heat loss. The solar collector helps in raising the temperature of compartment air higher than the surrounding temperature of the dryer. On the other hand, the remaining component called air flow system happens to serve as exit point where moist air moves to the environment (Ekechukwu and Norton, 1999a; 1999b; 1999c).

CLASSIFICATION AND MODE OF AIR MOVEMENT

According to Figure 2, solar dryers are classified according to the air flow movement, the mode of transfer of heat in the chamber and type of drying chamber (Elhage *et al.*, 2018).

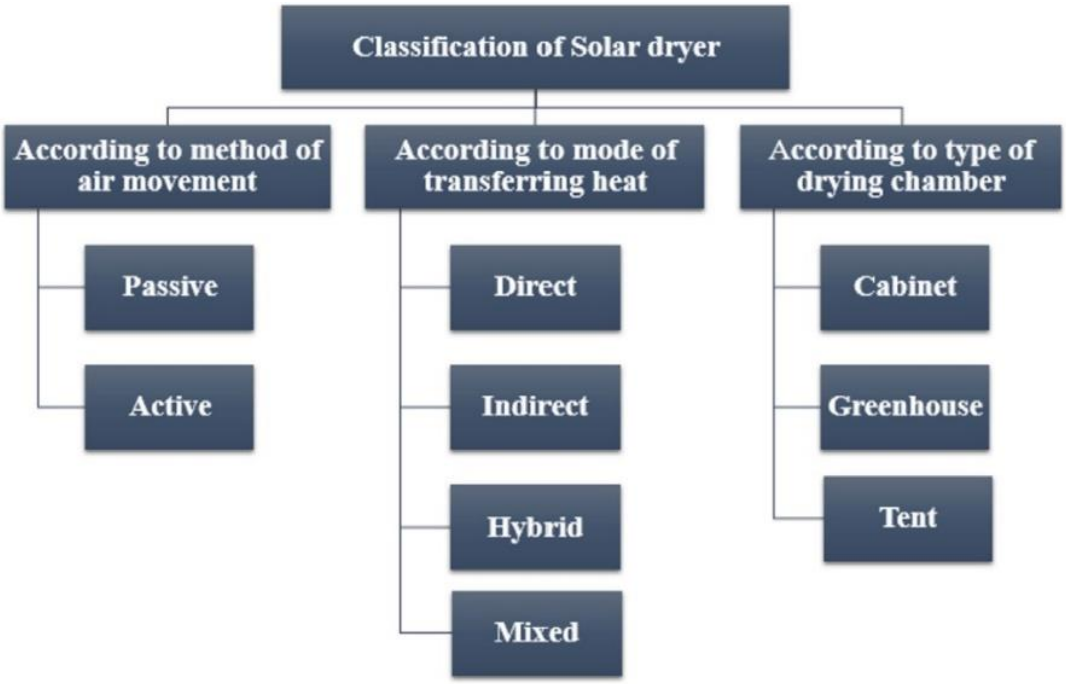
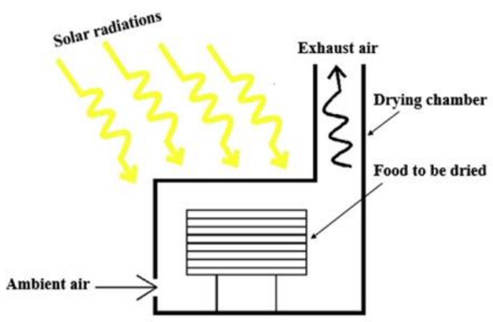


Figure 2. Classification of solar dryers (Elhage *et al.*, 2018).

Kumari *et al.* (2014) in a review paper showed several designs, detailed constructional features, and operational principles of a solar dryer system. Fudholi *et al.* (2010), on the other hand, presented a review of four types of solar dryers, which include direct dryer, indirect dryer, mixed dryer, and hybrid dryer. This was achieved by regarding the material to be dried, economic, and technical aspects. Over the years, the progress of solar drying systems of agricultural crop produce has been based on technical directions such the compact designs of the collector, and long-lasting drying system. Also, Elhage *et al.* (2018) research work showed the different types of solar dryers that are widely used. In addition to the active and passive type of solar dryers, it categorized dryers into indirect, direct and mixed dryers. Figure 3(a) and 3(b) shows the direct passive and direct active solar dryers while Figure 4(a) and 4(b) shows indirect passive and indirect active solar dryers.



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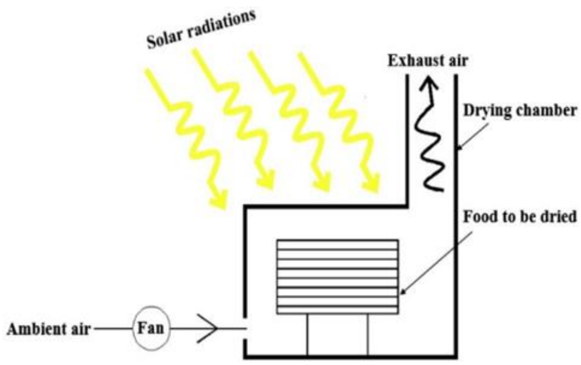

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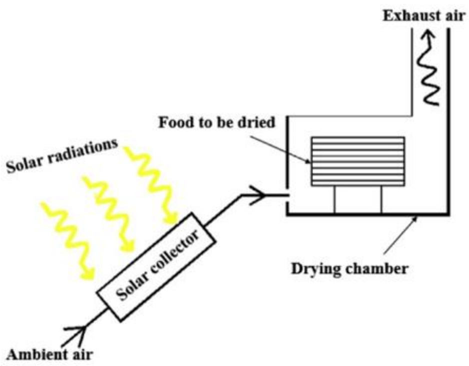
Figure 3. (a) Direct passive, (b) Direct active solar dryer (Elhage *et al.*, 2018).



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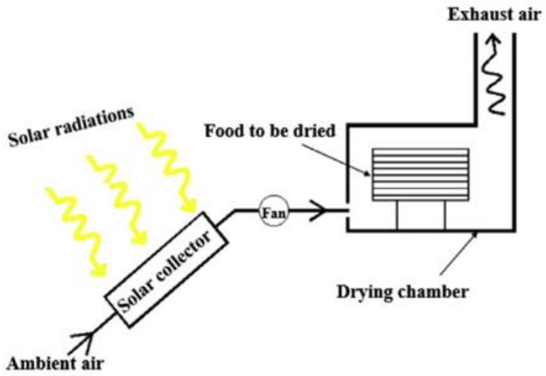

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Figure 4. (a) Indirect passive, (b) Indirect active solar dryer (Elhage *et al.*, 2018).

The figures above, also show the mode of air movement in the dryers, which on the long run affects the drying rate of the agricultural crop produce found in the drying chamber of the solar dryers. The passive solar dryer which is based on the natural movement of air have slow drying rate. This is a result of the slow movement of air across the drying chamber. This particular type of dryers are commonly known as natural convection solar dryers. The active solar dryers on the other hand, will require fan to move air through the dryer components. It could be mounted on either inlet or at the exit. They have higher drying rate due to the fan, but with the disadvantage of electrical energy being needed to operate the fan (Elhage *et al.*, 2018).

Mode of heat transfer

According to Zarezade and Mostafaeipour (2016), direct solar dryer is made up of the drying chamber which is covered by transparent glazing of plastic or glass. In direct solar dryer, crop produce is placed in an enclosure. The radiation from the sun is absorbed by the material and the internal surfaces of the drying chamber thereby generating heat. The generated heat evaporates moisture from the crop produce found inside the solar dryers leading to its drying. Bala and Debnath (2012) opined that, indirect solar dryer consists of drying chamber which has opaque cover, fan, solar collector. This solar collector may be fixed plate type of collector or concentrated type collector. In indirect solar dryer, the drying chamber is not exposed directly to solar radiation from the sun. Indirect solar dryer has a high drying rate compared to direct solar dryer. Moreover, air velocity, drying temperature and solid loading can simply be controlled in indirect solar dryer when compared to direct solar dryer (Kapadiya and Desai, 2014). Finck-Pastrana (2014), designed and studied the drying process of an indirect solar dryer.

Mixed mode solar dryer is the combination of direct and indirect types (Bala and Debnath, 2012; Stiling *et al.*, 2012; Prakash *et al.*, 2016; Sekyere *et al.*, 2016). The mixed mode solar dryer has the highest drying rate when compared with both direct and indirect solar dryers. Hybrid solar dryers are dryers that have both natural energy source (solar energy) and another energy source such as fossil fuel or biomass (Lopez-Vidana *et al.*, 2013; Reyes *et al.*, 2014; Kouchakzadeh, 2016). When compared to other dryers, hybrid dryers reduce the drying time of the agricultural produce to the barest minimum. These solar dryers on the other hand are very expensive to manufacture and definitely will lead to dependency on fuel. Drying rate of given solar dryers is affected by several parameters which include the type of material used in the construction of the dryers, its loading and pre-treatment method used, temperature found inside the dryer, the drying air velocity and lastly but not the least, relative humidity (Elhage *et al.*, 2018). Leon *et al.* (2002), gave detailed review of parameters that are generally used in testing and evaluating different types of agricultural crop produce in solar dryers.

SOLAR DRYING RESEARCH IN NIGERIA

In this article, the authors's aim to review some of the solar drying research carried out in Nigeria over the past few decades.

DISCUSSIONS

Igbeka (1986) opined that, the drying capacity of a passive solar grain dryer adaptable to rural farmers are affected by parameters like solar radiation, type of grain which will affect the air flow resistance, absorption of solar radiation and moisture movement. Also, moisture content of the grain at harvest, wind velocity and height variation among the air inlet and outlet of the dryer is very significant when the study was carried out. From the experimental results, a flat plate collector cum-dryer (Figure 5) gives best drying results when compared with a solar with a drying chamber and a flat plate collector with an in-bin storage (Figure 6). The social-economic standard of the farmers was not found to inhibit the adoption of the solar dryer while the use of locally available materials for construction of solar dryers was emphasized.

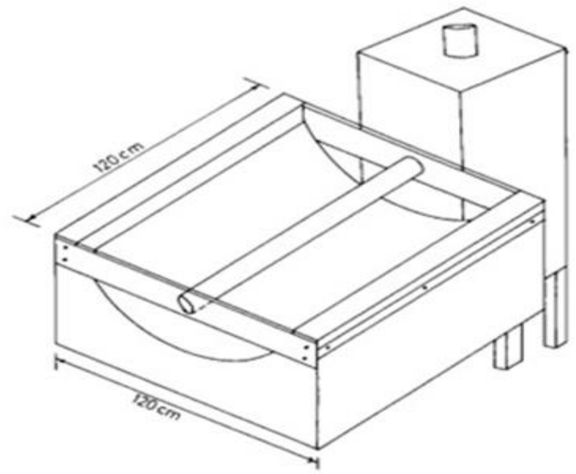


Figure 5. Flat plate collector (Igbeka, 1986).

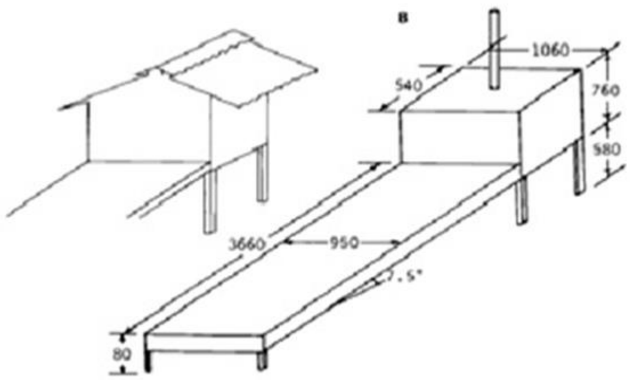


Figure 6. Flat plate collector with in-bin storage cum dryer (Igbeka, 1986).

Olufayo and Ogunkunle (1995) in their academic study of natural drying of cassava chips in the humid zone in Nigeria found out that, variations in the drying patterns of chips dried at about equal weight per unit area was very negligible. The parameters recorded and used to determine the results are the sunshine hours during the drying, daytime temperature when the experiment was carried out and relative humidity of the environment.

Ekechukwu and Norton (1998) research on effects of seasonal weather variations on the measured performance of a natural circulation solar energy tropical crop dryer, logical conclusion on performance of the dryer being dependent on variations in insolation, ambient temperature and relative humidity was significant. Also, the drying conditions during dry season was approximately constant. In wet season, drying conditions were significantly unpredictable which resulted in poorer drying. Isieka *et al.* (2012) research study on the effects of selected factors on drying process of tomato in forced convection solar dryer, found at 95% probability level, between the mean of three glazing materials used, there was no major significant difference. Mean slice thickness of tomato and Mean air flow rates shows high significant different when measured at 99% probability level. The result showed, an increase in air flow rate with corresponding decrease in material slice thickness leads to increase in the drying rate.

In the experimental research study on natural circulation solar air heating system (Figure 7) with phase change material energy storage by Enibe (2001), it was discovered that, there is a great potential for its applications in crop drying and poultry incubation. The system showed that, the peak temperature rise was around 15 K on the other hand, the maximum airflow rate and peak cumulative useful efficiency were about 0.058 kg s^{-1} and 22%, respectively. The single-glazed flat plate solar collector which happen to be integrated with a phase change material (PCM) heat storage system showed that, the system is suitable for agricultural drying. The experiment also showed that, when a suitable valve is available towards the control of the drying chamber temperature, it can also be used and operated as a poultry egg incubator.

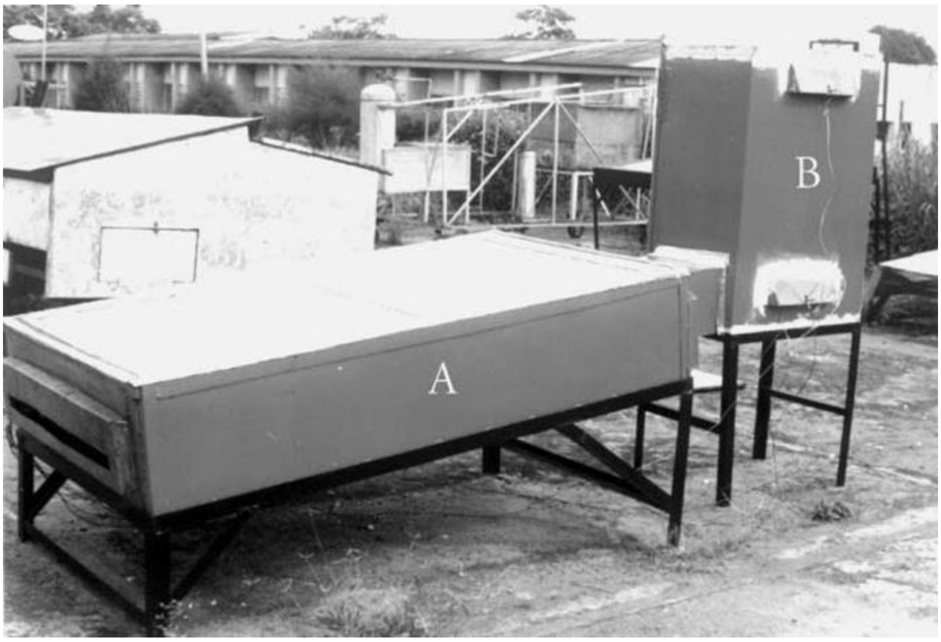


Figure 7. The air heating system (A-collector assembly with energy storage and air-heating subsystems; B-heated space) (Enibe, 2001).

In the evaluation of pebbled bed solar dryer, Okonkwo and Okoye (2005) found out that, moisture content of the cassava chips drops drastically from 73% to 10% (w.b.) when compared to open-air sun drying which reduced to 22.2% under the same period of experiment. They also observed that, the samples at different levels in the drying chamber trays were not drying at the same rate with the tray at the topmost having the highest drying rate. During the experiment, the absorber temperature was 72ºC, while the bed temperature for storing heat in the dryer was 58ºC. The chamber temperature of the dryer being 57ºC was noted when the maximum ambient temperature was 34ºC. It shows that, drying the cassava chips under solar dryer saves time and offer quality products as its advantages over open air sun drying.

Bolaji (2005), in his experimental study carried out regarding to the performance evaluation of a simple solar dryer found out that, inside the dryer with yam chips, the temperature from the heat source was higher than the ambient temperature in the drying process. In the experiment, the dryer was able to remove 72.8% of moisture (d.b.) in one day (10 h) experiment which shows a drying rate of 0.46 kg h^{-1}. After the experiment, he determined the system drying efficiency of the solar dryer as 59% despite using a locally available material for its construction (Figure 8).

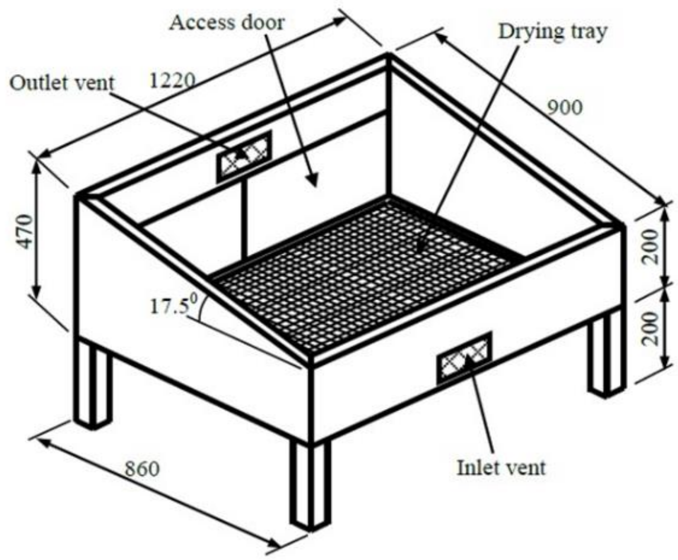


Figure 8. A simple solar dryer (Bolaji, 2005).

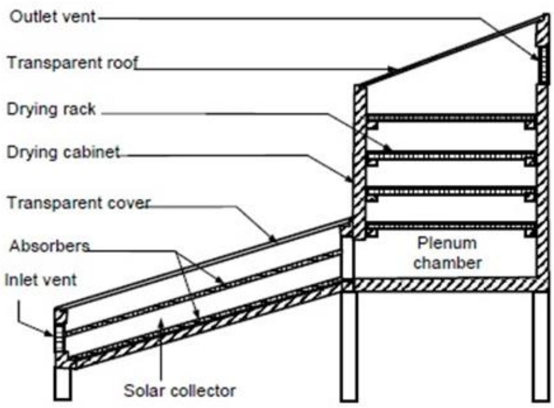
Akinola and Fapetu (2006) in their study on the evaluation of traditional and solar fish drying system in Nigeria noticed the predominant method adopted being the traditional methods in fish processing and drying methods. This result was obtained from the questionnaires administered to people in the sampled local governments and who have been in fish business for over 32 years.

Ezekoye and Enebe (2006) research on development and performance evaluation of modified integrated passive solar grain dryer, the drying crop produces (groundnuts and pepper) took maximum of 8 days and 5 days to dry when at average relative humidity of 43% and average temperature of 63°C. On one hand, the collector efficiency was 10% and dryer efficiency 22%. In the study on direct passive solar dryer for tropical crops carried out by Alonge and Hammed (2007), they got the maximum temperature of 59°C inside the dryer and 38°C outside under no load test condition. The cost of the dryer was cheap as a result of the use of local materials for its construction.

Akinola and Fapetu (2006) research on exergetic analysis of a mixed-mode solar dryer, was able to find average exegetic efficiency of 56% and thermal efficiency of 66.95%. It also showed, drying in a cabinet dryer made drying more attractive as well as conserve energy. Ozuomba *et al.* (2013) in the experimental research study on fabrication and characterization of direct absorption solar dryer, showed the technicalities involved in absorption solar dryer fabrication. The experiment also showed that the margin between the internal and external temperature was as high as 55°C with potential for its application in drying various agricultural products in addition to it being environment friendly.

Ajadi *et al.* (2007) carried out experimental study on effect of dust on the performance of a locally designed solar dryer, discovered dust as a limiting factor of solar thermal system. The result showed significant variation among the control and experiment dryers' temperatures. Ukegbu and Okereke (2013), in their research study on effect of solar and sun drying methods on nutrient composition and microbial load in selected vegetables; African spinach, fluted pumpkin and okra found out that, there were significant changes on the proximate analysis, vitamin, minerals and microbial load analysis on vegetable samples after drying. The study also showed that, solar drying of vegetables led to retaining of more nutrients and is relatively hygienic with reduced microbial. Okoroigwe *et al.* (2015) in research study on comparative evaluation of the performance of an improved solar-biomass hybrid dryer, it was found that, a redesigned biomass solar dryer with a back pass solar collector and heat exchanger showed a significant improvement in agricultural drying. The efficiency of the solar dryer based on solar, biomass and a combined solar biomass showed a significant increase in the drying of fresh okra, fresh groundnut and fresh cassava chips when a test was carried out. Irtwange and Adebayo (2009) research experiment on development and performance of a laboratory scale passive solar grain dryer in a tropical environment, the mean drying rate of the 10 kg of freshly harvested maize to be 0.7 kg day^{-1} was determined while in direct comparison with sun drying, the drying rate of 0.3125 kg day^{-1}. Its advantages over the traditional sun drying methods include faster drying rate, reduction of spoilage by microorganisms and handling convenience. Musa (2012) carried out experiment on the drying characteristics of cocoa beans using an artificial dryer, it was found that high drying rates were achieved easily when there is increase in drying air temperature and velocity in the given solar dryer.

In the experimental evaluation of the performance of a mixed-mode solar dryer (Figure 9) carried out by Bolaji and Olalusi (2008), the drying rate and system efficiency of the mixed mode dryer after the analysis of the data was 0.62 kg h^{-1} and 57.5% respectively.



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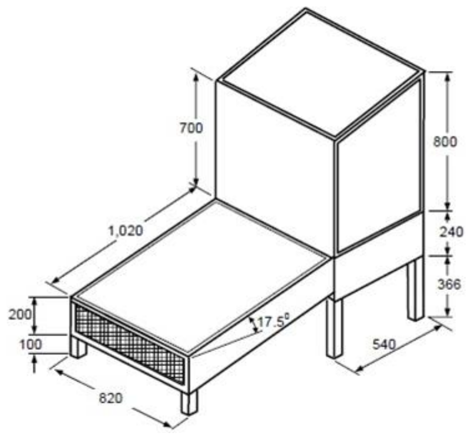

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Figure 9. View of mixed-mode solar dryer (Bolaji and Olalusi, 2008).

Ajao and Adedeji (2008) in their research study regarding to the assessment of the drying rate of some crops in solar dryer, it showed average value of the tropical crop (Yam) drying rate was 9.0 g h^{-1} which had system drying efficiency of 18% while on other hand, the lowest drying rate was for pepper at 1.6 g h^{-1}. The experiment proved that the drying occurs under constant rate falling period and decreases when the material moisture content is less than maximum hygroscopic content. Ekechukwu and Norton (1999a) in their research review of solar energy drying systems study carried out a detailed review of various designs and performance evaluation of flat-plate solar energy collector for low temperature. The appropriateness of each design and the component materials selection guidelines was actualized and concluded to be a useful parameter to be considered. In their study, where higher temperature is desired, double or triple-glazed solar energy air heater can be used. This helps to reduce drastically the upward convective and re-radiative heat losses. Dairo *et al.* (2015), during experimental study of solar dryer kinetics of cassava slices in a mixed mode flow dryer discovered that, between the 10 commonly used thin layer drying models for drying curve modelling of the cassava slices, there was significant changes. The Midilli and Logarithmic Models showed better fit to the experimental drying data of cassava slices.

Aliyu and Jibril (2009), research on utilization of greenhouse effect for solar drying of cassava chips found, over 30% savings in drying time was achieved in the dryer. This is a great savings when compared to open-air sun drying. Also showed that, the organoleptic quality of the cassava chips is great as a result of retaining their white color (indicating no growth of mould). Fagunwa *et al.* (2009) in their experimental research study on the development of an intermittent solar dryer for cocoa beans discovered cocoa beans showed good qualities during its quality assessment. When free convective drying was used, pH of 6.35, acid value of 3.40 mg g^{-1} with mildly bitter taste were obtained while using convective solar dryer, increase in moisture re-absorption and acidic flavor were obtained. The cocoa seeds were successfully dried from initial moisture content of 53.4% (w.b.) to safe moisture level 3.6% (w.b). Lawrence *et al.* (2013) research on design, construction and performance evaluation of a mixed mode solar dryer, it was found that average dryer temperature to be 40.9 ºC. 100 kg holding capacity mixed mode solar dryer was incorporated with a black painted conical chimney. This serves as an additional absorber with the experimental test carried out at 10%, 25% and 50% load capacity for the cassava chips. Result showed the drying rates varies with coordinate position of trays. It decreases from the bottom up to a minimum, at the middle of the tray and starts increasing up to the top tray.

Yohanna and Umogbai (2010) while reviewing the solar energy potential in Nigeria, listed the various sectors it could be utilized such as crop drying, poultry production, manure drying, dairy production, irrigation and water pumping, refrigerated food, vaccine and drug storage etc. They also recommended the expansion of solar energy supply schemes to the rural areas in Nigeria.

Eze and Agbo (2011), in their comparative study of the research topic on sun and solar drying of peeled and unpeeled ginger, was able to find, the moisture content of the solar dried unpeeled ginger was drastically reduced to 7.0% (w.b). This falls within the acceptable international market standard of 6%-9%. The experiments also show that, open-air sun-dried crop produce retain its colour and aroma more than the solar dried samples.

Ugwu *et al.* (2011) in their experimental study on impact of vehicle emissions and ambient atmospheric deposition common in Nigeria on the Pb, Cd and Ni content of fermented cassava flour processed under the sun discovered, the higher the concentration of the emissions on the fermented cassava, the higher its effects. The average concentration of the element in sun-dried samples were greater ($p \leq 0.01$) while when it was on the roadside, they were 185% in Pb, 53% in Cd and 176% in Ni greater than atmospheric condition. The results also showed that, Pb emissions from petrol. diesel with dust is among those considered as the major source of Cd, Ni and other extraneous factors including metals adsorbed on pavements surfaces. Open-sun drying of wet foodstuff on the bare surface of roadside could potentially lead to high levels of Pb, Cd and Ni in food produce when compared to drying under conducive conditions or oven-drying.

In the research topic on the design and fabrication of a direct natural convection solar dryer experiment carried out for tapioca by researchers Ogheneruona and Yusuf (2011), they determined, a minimum of 7.56 m^2 solar collector area is the right area to dry a given batch of 100 kg tapioca in 20. In the experiment, the final moisture content of the drying material - tapioca was 10% (w.b.) which falls from the initial moisture content of 79% (w.b.). During the experimental research study by Okoroigwe *et al.* (2013) in their research evaluation regarding to the design and evaluation of combined solar and biomass dryer for developing countries, it was found by them that, the drying efficiency of the solar dryers where greatly maximized when it was combined with biomass as a source of its heating. The results showed that, the optimal drying rate of 0.0142 kg h^{-1} was actualized when with combined solar and biomass dryer as when it was only solar drying or biomass drying which happen to have drying rates of 0.00732 kg h^{-1} and 0.0032 kg h^{-1} respectively. In the performance evaluation of a solar wind-ventilated cabinet dryer experiment (Figure 10) carried out by Bolaji *et al.* (2011) shows that, the dryer performance depends on the proper air circulation through the system. Comparatively, the increase in the air velocity through the system leads to a significant increase in the system efficiency.

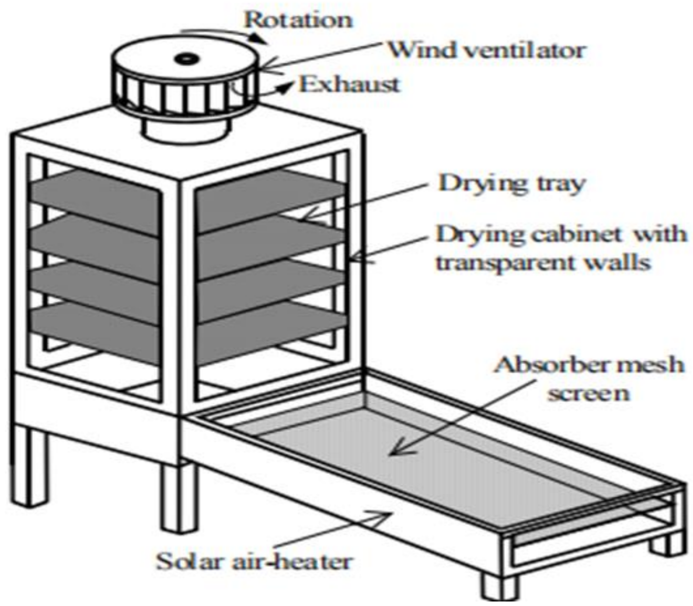


Figure 10. Solar wind-ventilated cabinet dryer (Bolaji *et al.*, 2011).

Alonge and Adeboye (2012) in their evaluation study of the drying rates of some given fruits and vegetables, obtained that direct passive solar dryer gives better results when the fruits like pepper, okra and vegetables were dried as regards to indirect passive solar dryer. The experiment also helped in confirmation of other research works carried out by showing that, the drying rate of the crops occurred in falling rate period.

Babagana *et al.* (2012) research on design and construction of forced/natural convection solar vegetable dryer with heat storage discovered that the drying rate and time of the forced mode solar dryer used for drying tomato, onion, pepper, okra and spinach vary significantly from natural mode solar dryer. The collector efficiency was 45% and useful heat of 48.9 W $m^{-2}K^{-1}$ was used for about 6 h in drying during the night. Hussein *et al.* (2017) research on the design, construction and test of a hybrid photovoltaic solar dryer showed that, it took 6 h to reduce the moisture content of tomato slices from the initial value of 94.22% to the final value of 10% (w.b.). This is different to the 9 h it took to achieve same moisture content when solar dryer was used. Average drying rate and efficiency determined during the experiment were 0.800 kg h^{-1} and 71% for hybrid solar dryer and 0.0578 kg h^{-1} and 65% for combined solar-energy dryer.

Eze and Ojike (2012) experimental study on effect of different dryers on vitamin content of tomato, the concentrations of Vitamin A, C and E between the fresh samples and dried samples for all drying systems was able to show significant difference. The study also showed that, Vitamin A and E are increased significantly with open-air sun drying system having the highest value in Vitamin C concentration. Latitudinal box dryer (Figure 11) on the other hand gave the best result in terms of vitamin A and E retention in direct comparison with greenhouse solar dryer (Figure 12) and sun-tracking solar dryer (Figure 13). It proved drying tomatoes using solar dryer enhances the concentration of fat-soluble vitamins in direct comparison to open-air sun drying system which enhances water soluble vitamins better.

Figure 11. Latitudinal box solar dryer (Eze and Ojike, 2012).

Figure 12. Greenhouse solar dryer (Eze and Ojike, 2012).

Figure 13. Sun manual tracking solar dryer (Eze and Ojike, 2012).

Aliyu *et al.* (2013) in experimental study of the performance evaluation of a village-level solar dryer for tomato under savanna climate discovered that, the drying temperature and drying rate was higher than the natural open-air sun drying method. Results showed drastic reduction of the tomato moisture content to 4% (w.b) while on the otherhand, the solar dryer efficiency was 64%, air flow rate 0.025 kg s^{-1} and drying rate of the crop produce 0.03906 kg h^{-1}. Nwoke *et al.* (2011) experimental study on the analysis and survey of the application of solar dryers in Eastern Nigeria, were able to find on the domestic and industrial level, the practical use of solar dryers is absent. These results were gotten from oral interview and administration of questionnaire to the local farmers as well as the rural populace. Also, there was great enthusiasm among the farmers in the use of solar crop dryers if their performance is satisfactory with respect to quality and quantity of products although the rejected the idea of establishing a communally maintained and operated solar drying system. Preference for commercialized solar drying system where payments would be made per unit quantity of products dried was commonly agreed by the farmers. Recommendation on the establishment and development of affordable solar crop dryers with auxiliary heat sources to mitigate the effects of daily and seasonal fluctuation in solar system was reached by the researchers.

Oko and Nnamchi (2013) in their experimental research study on coupled heat and mass transfer in solar grain dryer, they noticed, good agreement between the theoretical and experimental results at specified Biot and Posnov numbers in addition to varying Fourier number. From their study, it could be used to specify the design parameter for solar grain dryers. In the experimental set up by Anyanwu *et al.* (2012) to investigate a photovoltaic-powered solar cassava dryer, they discovered, the system is structurally and functionally operative which is capable of handling 50 kg of fresh corn per batch. Despite the active solar dryer being expensive, it happened to be suitable for application in rural, off-grid agricultural settlements in Nigeria.

Eke (2013) in his experimental study discovered that, when direct mode natural convectional solar dryer (Figure 14) was used to dry tomatoes, okra and carrots, over 50% gain was obtained in the drying time when compared with open-air sun drying carried out at the same time. Also, even though the solar dryers' efficiency ranges between 21%-25% for the vegetables, it was far better than open air sun drying which has highest system drying efficiency of 15.9%. The experimental results show that, onions cannot be dried in the open air due to loss of its aroma and the best way to preserve vegetables is by using solar dryers.

Figure 14. The direct mode natural convection solar dryer for carrot, tomato and okra (Eke, 2013).

Eke (2014) in his investigation, on the research topic: low-cost solar collector for vegetable drying in rural areas (Figures 15-18) determined that, mud as a material for building the solar collector is cheaper and readily available in the Northern region of Nigeria in comparison with metal, wood or cement materials. The evaluated data obtained from the drying of sliced tomatoes on the solar dryers constructed with these materials shows that, metal plate solar collector offers the highest system drying efficiency of 27.24%.

Figure 15. Solar dryer constructed with metal plate solar collector (Eke, 2014).

Mustapha *et al.* (2014) in their experimental research study on the proximate analysis of fish dried using solar dryers, was able to notice the final moisture content of the 2 species of fishes dried being around 10.77% (w.b.)-11.20% (w.b.) (*C. gariepinus*) and 6.80% (w.b.)-7.82% (w.b.) (*O. niloticus*). Other analysis showed that, the fiber was low in the two species, with regards to fat, it was 8.19-8.96 (*C. gariepinus*) and 6.80-7.82 (*O. niloticus*), in protein, was 64.88-66.48 (*C. gariepinus*) and 58.75-63.28 (*O. niloticus*). It shows nutrient compositions of the species dried with solar dryers were very high, hygienic, better, more preserved and acceptable. Ezeanya *et al.* (2018) research on the modelling of a thin layer solar drying kinetics of cassava noodles (Tapioca), found the Modified Aghbashlo Model was the best fitted to the drying data of tapioca. Data obtained using a forced convection solar dryer with the treatment combination of the experiment comprises air flow velocities (V) of 1.5, 2.5 and 3.5 m s^{-1}, in the drying layer, thickness (B) of 0.48 cm and 0.72 cm and lastly, in the initial moisture contents (M_i) of 297%, 186% and 122% (d b).

Figure 16. Solar dryer constructed with wood solar thermal collector (Eke, 2014).

Figure 17. Solar dryer constructed with cement thermal solar collector (Eke, 2014).

Figure 18. Solar dryer constructed with mud solar thermal collector (Eke, 2014).

Ugwu *et al.* (2014) in their study of a mixed mode solar kiln with black-painted pebble bed for timber seasoning (Figure 19) found out that, it was an efficient system for wood seasoning. During the peak periods, timber stacked in the drying chamber receives hot air flow from the collector and the transparent roofs simultaneously with the maximum drying chamber temperature being 61.7°C. Kiln drying reduce the timber moisture content of the dryer from the initial moisture content of 66.27% (d.b.) to 12.9% (d.b.) while on the other hand, open-air sun drying was reduced to 20.1% (d.b.) in 360 h of drying process. The rapid rate of drying in kiln showed, the ability to dry timber to the barest level without defects when compared to open-air sun drying.

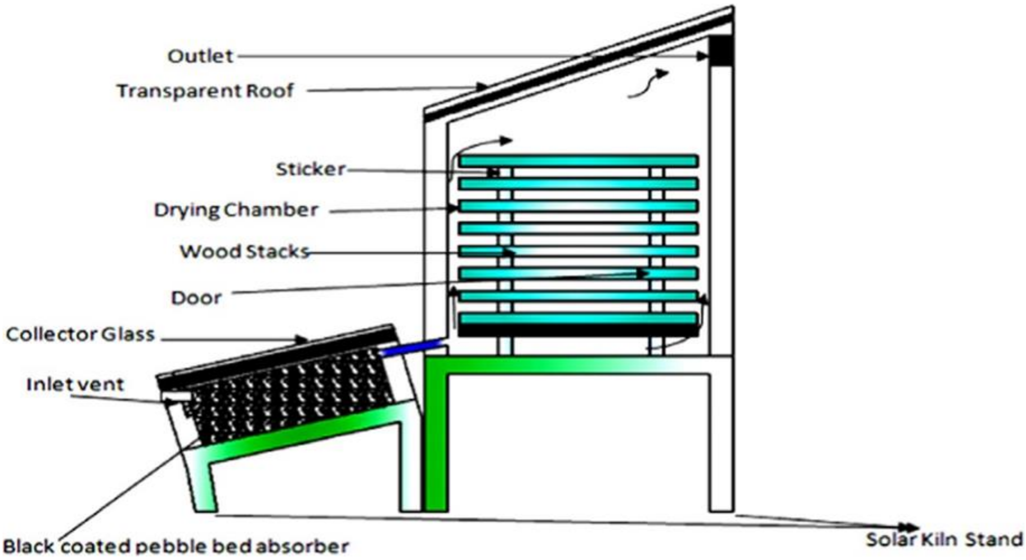


Figure 19. Cross-sectional view of mixed-mode passive solar dryer with pebble bed (Ugwu *et al.*, 2014).

Ibrahim *et al.* (2015) research on the drying of chili pepper using solar dryer with a backup incinerator under Markudi humid climate showed drying occurs under a falling rate period. The drying efficiencies for solar dryer and combined solar-incinerator dryer were 99.6% and 92.9%, respectively. In the study on integral type natural-circulation solar-energy tropical dryer done by Ekechukwu and Norton (1995), it was discovered a direct linear correlation of the measured data for a grouped parameter of ambient and crop properties against moisture content. This helped in forming solar dryer design charts. Ogunkoya *et al.* (2011) research study on development of a low-cost solar dryer found out that it cost approximately $40 (US Dollar) for a solar dryer fabricated with locally sourced materials. In addition, Abubakar *et al.* (2018) previously studied on development and performance of a mixed-mode solar dryers with and without thermal storage, efficiency of the dryers with storage materials enhanced greatly by 13% which was as a result of the thermal storage used. Okoroigwe *et al.* (2013) research study on design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries, dryers have potential to increase the productivity and resultant economic viability of small and medium scale in developing countries. An optimal drying rate of 0.0142 kg h^{-1} was achieved with the combined solar-biomass dryer when it happened to be compared to the lower drying rate of 0.00732 kg h^{-1} for solar drying and 0.0032 kg h^{-1} for biomass dryer. Adeuwa *et al.* (2014) in the study on the development of hot air supplemented dryer took 13 h to dry yam slices in comparison to the solar dryer which took 18 h. The average thermal efficiency for both solar dryer and hot-air supplemented solar dryer are 31.45% and 42.10% respectively when the measurement was carried out.

Okeke *et al.* (2015) in research study on drying of Nsukka beans using a solar dryer found that, result was achieved when a 10 kg beans were successfully dried and reduced to 6 kg. The system drying efficiency was 40%. In the study carried out by Ikrang *et al.* (2015) research on the development of a direct passive solar dryer for crayfish, it was discovered that, crayfish exposed to open sun drying were infested with maggots as a result of contamination by flies and microorganism. In different drying with solar dryer, good crop produce was obtained which had good appearance and better colour. Their experimental result also showed that, it took approximately 3 days (at 9 hourly drying) to reduce the moisture content of the crayfish from initial moisture content of 76.60% to final moisture content12.00% (w.b.) when solar dryer was used unlike 5 days that was obtainable in open-air sun drying.

Adepoju and Osunde (2017) in their experimental study regarding to the effect of pre-treatment and drying methods on some qualities of dried mango fruits, discovered that, sun and solar drying of pre-treated mango slices took 8 h while on the other hand, the oven drying took 6 h at an average temperature of 32°C, 41°C and 65°C respectively. From the result, pre-treated methods used did not have effect on the drying rate. Also, proximate composition of the pre-treated dried mango samples revealed rich Vitamin C and B carotene (antioxidant) which makes them healthy and nourishing.

In the experimental study on effect of drying methods on the yield, phytochemical composition and antioxidant activities of potato and sweet potato carried out by Kolawole *et al.* (2018), it showed the floor yield varied significantly when evaluated using open-air sun drying and solar drying. The total antioxidant activities in the crop produce was significantly affected by the drying methods in the experiment. The effect of open-air sun-drying was less favorable on the white fleshed sweet potato samples in direct comparison with solar drying method. From their study, it was discovered, the direct dependency of the tubers on drying methods on yield, phytochemical and antioxidant activities of the sample. Iwe *et al.* (2018) in the experimental evaluation towards the mathematical modelling of a thin layer solar dryer of Ighu (dried cassava slices used to prepare a meal commonly called African salad) determined, the effects on drying time by applying different air plenums, different loading densities as well as different moisture contents in direct relation to open-air sun drying method which was used as the control experiment. The experimental moisture ratios of the samples obtained during the experiment was fitted to nine drying models. The testing of the mathematical models with the drying behavior of Ighu, the Page model and Modified Page model happened to be the best model based on statistical parameters of coefficient of determination, root mean square error and reduced mean square errors. This is applicable towards predicting moisture content of Ighu samples during solar drying and open-air sun drying.

Abubakar *et al.* (2018) built a mixed-mode solar crop dryers with and without thermal storage materials and tested under Nigerian climatic conditions (Figure 20). The dryer consists of solar collector, drying chamber, chimney and shelves. According to the results, drying efficiencies were found 28.75% and 24.20% with and without thermal storage, respectively.

Komolafe and Waheed (2018) designed and fabricated a 10 kg capacity forced convection solar dryer integrated with thermal energy storage materials. The dryer consists of a solar collector, drying chamber and photovoltaic components (Figure 21). The maximum collector and drying chamber temperatures reached to 91.3ºC and 70.8ºC at higher solar radiation values. In drying experiments of cocoa beans, drying time was 10 h, while it was 58 h for natural sun drying. So, the solar dryer was capable for drying products within short time.

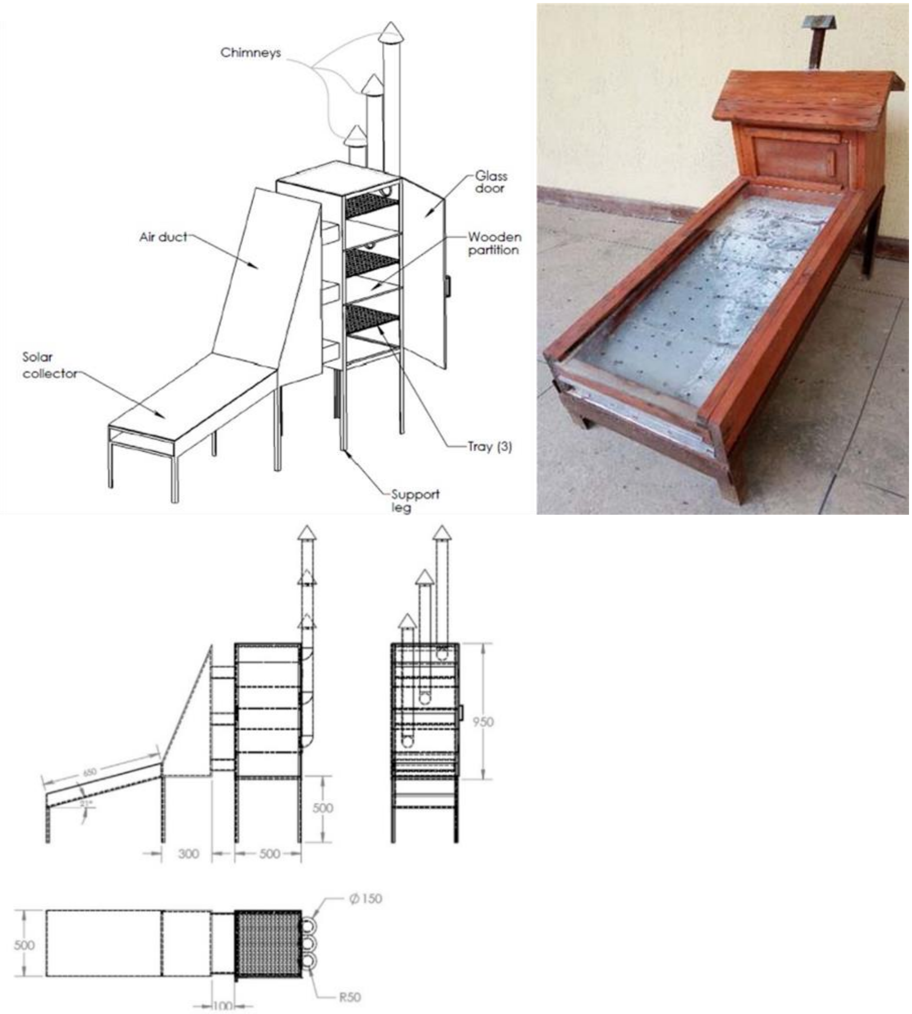
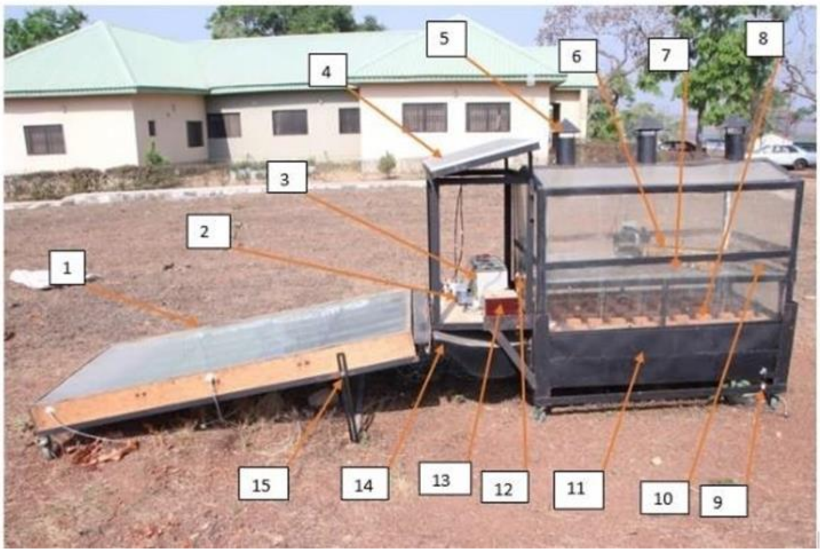


Figure 20. Mixed mode solar dryer (Abubakar *et al.*, 2018).

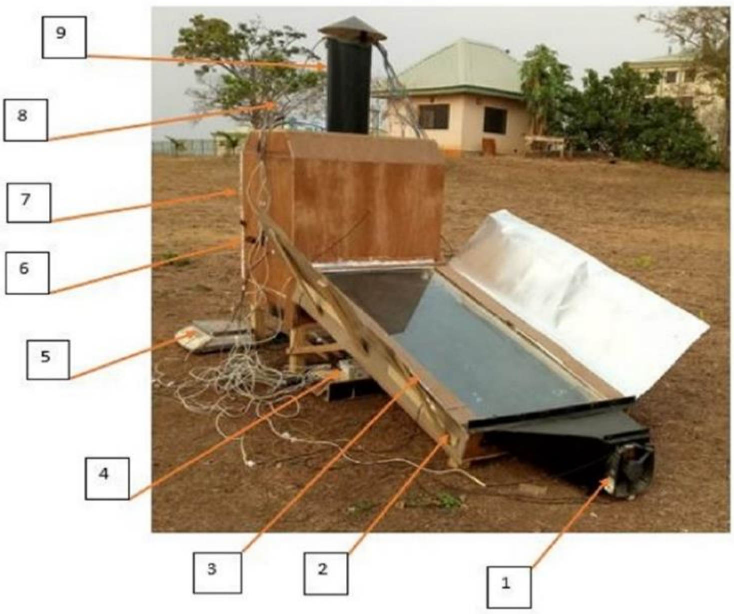


(1-Solar collector box; 2-Charge controller; 3-Battery; 4-Solar cell; 5-Chimney; 6-Stirrer; 7-Drying tray; 8-Thermal storage material; 9-Supporting frame; 10-Drying chamber; 11-Plenum chamber; 12-Thermostat; 13-Stirrer control box; 14-Air duct with blower; 15-Collector box supporting hanger).

Figure 21. Picture of the fabricated solar dryer (Komolafe and Waheed, 2018).

Kilanko *et al.* (2019) designed, constructed and evaluated the performance of solar dryer with a dimension of 1000x410x700 mm (Figure 20). In experiments, fresh scotch bonnet pepper was dried to the safe moisture content. According to the results, the mean dryer efficiency was found as 28.4%. In addition, the use of solar dryers has growing interest for the agricultural sector especially in locations of high solar insolation. The quality of produce obtain via this method provides longer shelf life and greater sale value.

Komolafe *et al.* (2019) investigated the thin layer drying behaviour of locust beans under forced and natural convection mode solar dryer with thermal storage materials (gravel) (Figure 22).



1-Blower; 2-Solar collector; 3-Reflector; 4-Data acquisition system; 5-Weighing balance; 6-Thermostat; 7-Drying chamber; 8-Temperature and humidity sensors; 9-Chimney.

Figure 22. Forced convection solar drying system (Komolafe *et al.*, 2019).

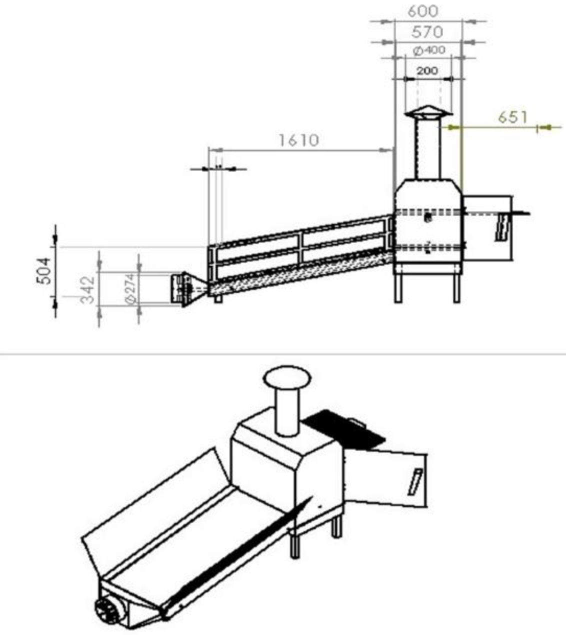
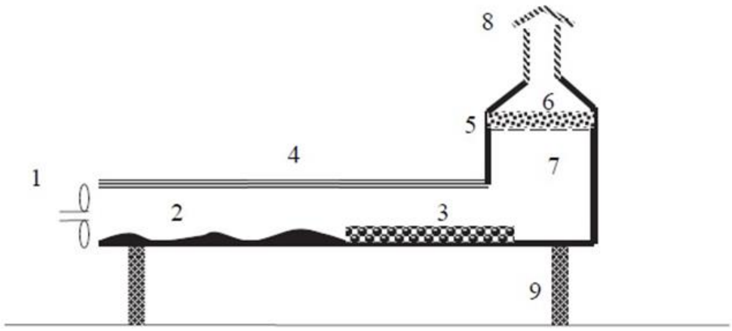


Figure 22. Continue (Komolafe *et al.*, 2019).

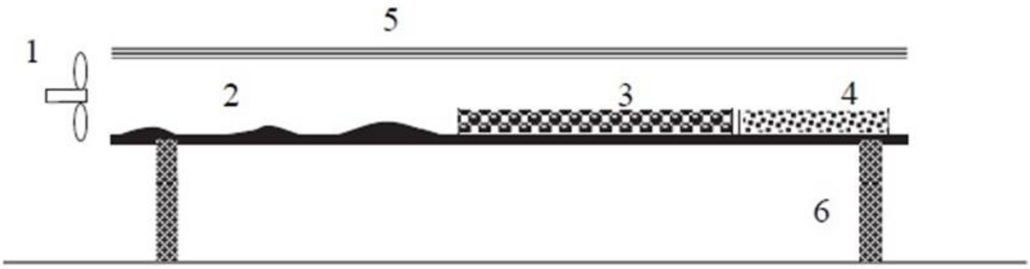
Itodo *et al.* (2019) emphasized that, humid tropical regions with nearly more than 70% ambient relative humidity for whole year, require desiccant augmented dryers. So, three types of non-regenerative desiccant solar crop dryers, indirect-active desiccant dryer (IADD) (Figure 23 and 24), direct-active desiccant dryer (DADD) (Figure 25 and 26), and the direct-passive desiccant dryer (DPDD) (Figure 28 and 29) were evaluated than compared with open air sun drying (OASD) by the drying rate (kg h^{-1}) and dryer performance coefficient (DPC). The desiccant used was a composite of rice husk ash (RHA) and calcium chloride binded with cement in the ratio of 1:1:1 by weight. According to the results, the drying rates were 0.23, 0.19, 0.16, and 0.13 kg h^{-1} for the DADD, DPDD, IADD, and OASD, respectively. The drying rate of the OASD was not significantly different from that of the IADD. The DPC was 1.53, 1.40, and 1.15 for the DADD, DPDD, and IADD, respectively. The DPC of the dryers were significantly different. The direct active desiccant dryer had the highest temperature of 45°C, the lowest relative humidity of 50% at the drying unit and the highest rate of moisture absorbed by the desiccant of 0.24 kg h^{-1}. The non-regenerative RHA desiccant had maximum moisture absorption of 28% of its weight. The direct active desiccant dryer is recommended for further development for use in humid tropical locations.



1-Fan; 2-absorber; 3-desiccant bed; 4-transparent cover; 5-grain tray; 6-grains; 7-drying chamber; 8-chimney; 9-wood support.

Figure 23. Cross-sectional view of the indirect-active desiccant solar crop dryer (Itodo *et al.*, 2019).

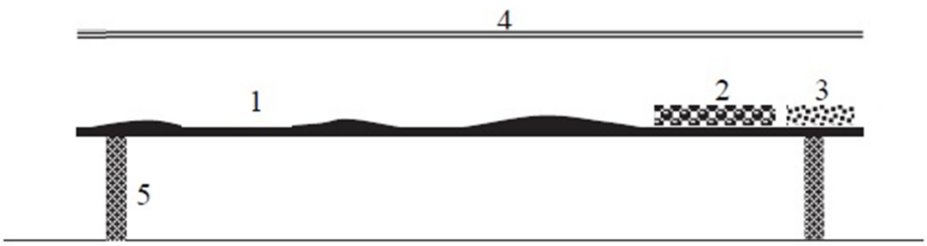
Figure 24. The indirect-active desiccant solar crop dryer (Itodo *et al*., 2019).



1-Fan; 2-absorber; 3-desiccant bed; 4-grain; 5-transparent polythene cover; 6-wood support.

Figure 25. Cross-sectional view of the direct-active desiccant solar crop dryer (Itodo *et al*., 2019).

Figure 26. The direct-active desiccant crop dryer (Itodo *et al*., 2019).

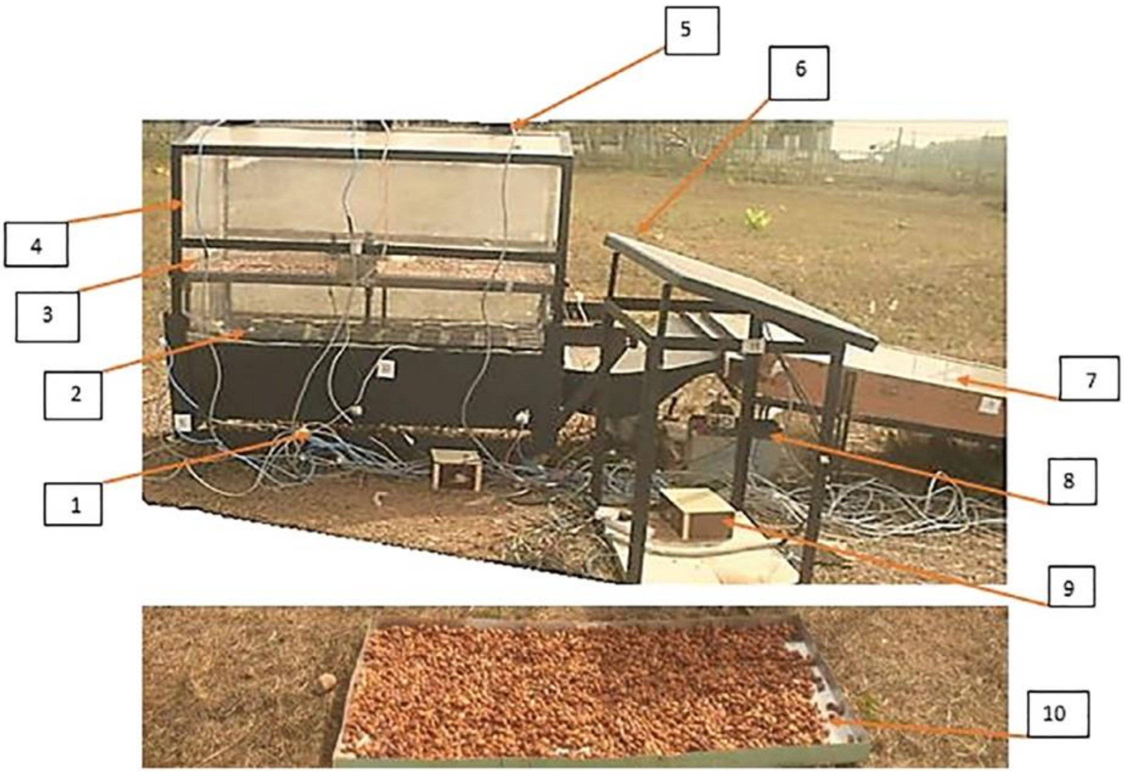


1-Absorber; 2-desiccant bed; 3-grains; 4-transparent polythene cover; 5-wood support.

Figure 27. Cross-sectional view of the direct-passive desiccant solar crop dryer (Itodo *et al.*, 2019).

Figure 28. The direct-passive desiccant solar crop dryer (Itodo *et al.*, 2019).

Komolafe *et al.* (2020) dried cocoa beans using open-sun and a force convective solar drying (SD) system with a capacity of 10 kg.



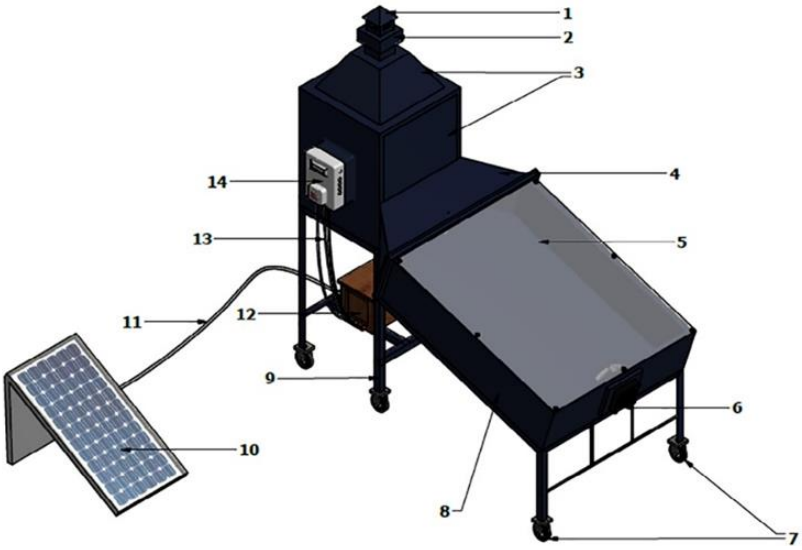
1-Temperature and humidity sensor cables; 2-Heat storage materials platform; 3-Drying chamber; 4-Supporting frame; 5-Chimney; 6-Solar panel; 7-Solar collector; 8-Battery/inverter/charge controller; 9-Data logger housing; 10-Open-sun drying.

Figure 29. Pictorial view of the experimental set-up (Komolafe *et al.*, 2020).

Ndukwu *et al.* (2020a) investigated the drying of potato slices with an active mix-mode wind-powered fan and with a passive mix-mode non-wind-powered solar dryers with and without thermal energy storage. Results showed that, active mix-mode wind power fan solar dryer with energy storage took shorter drying time. The energy consumption changed between 4.10 to 4.98 MJ, while the specific energy consumption ranged from 2.85 to 3.69 kWh kg^{-1}. The drying efficiencies ranged from 25.03% to 31.50%. This naturally powered fan with any place without electricity would supply shorter drying times and also saving about 15.3 to 290.4 $ per year (Figure 30).

Figure 30. Developed prototype solar dryer without and with a wind generator (Ndukwu *et al.*, 2020a).

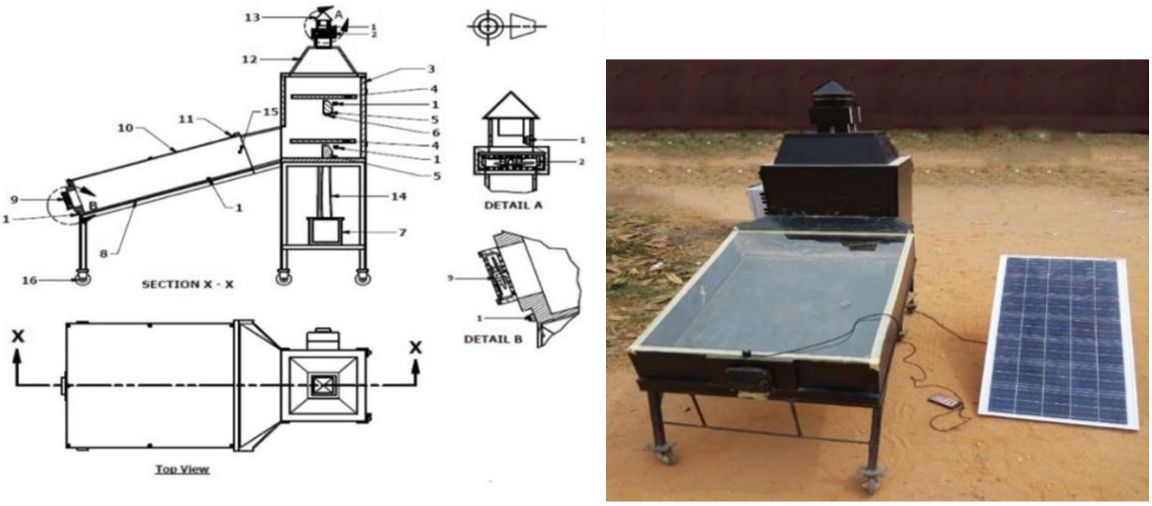
Nwakuba *et al.* (2020a) used an active hybrid solar-electric dryer to dry tomato slices (Figure 31). The study examined the effects of varying process parameters such as drying air temperature, sample thickness and air velocities on the total and specific energy requirements, drying time, lycopene content, ascorbic acid and color properties. The results showed that, the total and specific energy requirements for a batch of tomato varied from 7.82 to 125.48 kJ h^{-1} and 6.70 to 179.83 kJ hg^{-1}. In addition, optimum drying conditions were found as 57.28°C, 14.08 mm, and 1.3 m s^{-1}, and the specific energy requirement, lycopene content, ascorbic acid content, nonenzymatic browning index, brightness, redness to yellowness ratio, and drying time were 103.3 kJ hkg^{-1}, 58.7 mg 100mg^{-1} dry matter, 2.9 mg g^{-1}, 0.51 absorbance unit, 60.07, 0.77 and 61.88 minutes, respectively. It was announced that, the improved dried tomato quality could be obtained together with higher dryer energy efficiency and cost-effectiveness.



1-Chimney; 2-Outlet/Exhaust fan housing; 3-Drying chamber hood; 4-Heating chamber; 5-Plain glass; 6-Inlet sensor fan; 7-Rollers; 8-Solar collector; 9-Angle iron support; 10- Solar panel; 11-Solar panel cable; 12-Inverter/Battery unit; 13-Control unit cable; 14-Control unit.

Figure 31. Isometric view of the hybrid solar dryer (Nwakuba *et al.*, 2020a).

Nwakuba *et al.* (2020b) developed hybrid solar-electric dryer (HSED) and investigated during the rainy season (Figure 32). In this study, thermal characteristics, drying efficiency of the dryer at diferent conditions for 1.5 kg fresh sliced tomato samples. According to the results, the total and specific energy consumption of tomato slices changed between 5.61-120.31 kJ h and 5.18-167.59 kJ hg^{-1}, respectively. The energy contribution by solar and electric heat units varied between 44.57-56.24% and 43.76-55.43%, respectively. Drying time and drying efficiency ranged between 130 and 330 min and 4.33-36.38%, respectively. The average energy efficiency of the hybrid system increased from 15.67 to 38.17%. According to the results of economic analysis, an amount of about 1490 $ could be saved per year by using this solar dryer with a payback period of 0.72 years.



1-Temperature/Humidity sensors; 2-Exhaust fan; 3-Door frame; 4-Drying racks; 5-Weighing balance; 6-Iron bar (support); 7-Battery/Inverter assembly; 8-Solar collector; 9-Inlet fan; 10-Plain glass; 11-Screw bolt; 12-Drying chamber hood; 13-Chimney; 14-Cable; 15-Heating element; 16-Roller.

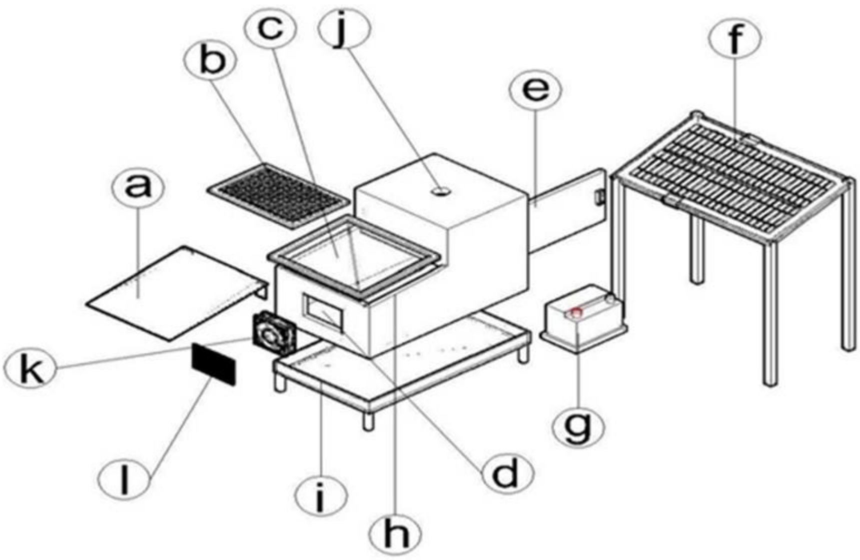
Figure 32. Hybrid solar-electric dryer (Nwakuba *et al.*, 2020b).

Ndukwu *et al.* (2020b) designed, fabricated and tested a low-cost hybrid solar drying system with and without biomass heater (Figure 33). The results showed that, drying time could be reduced between 27.78% and 58.33% by using solar dryer when compared to open sun drying method for 5 mm thick plantain slice. The average drying efficiency was found between 8.4% and 14.64% for solar dryers.

A-solar dryer without biomass heater; B-side view of the array of the two solar dryers with the biomass heater furnace open; C-solar dryer showing the biomass heater furnace covered and the door open; D-the biomass heater with the cylindrical pipe in place to create the flue gas duct during feedstock loading; E-biomass furnace revealing the connection of the exit pipe into the combustion chamber; F-sun drying of the plantain slices

Figure 33. Prototype of the indirect solar dryer (Ndukwu *et al.*, 2020b).

Etim *et al.* (2020) designed and constructed active indirect solar dryers for drying of banana. The dryers were constructed with different air inlet shapes. Total of 52 dryers were required for the experimental design (Figure 34 and Figure 35). According to the results, the dryers were able to conserve almost 40% of the total drying time for the products when compared to natural open sun drying. The efficiency of the driers changed between 13.85 to 31.84%. It was observed that the air inlet area of the dryer had significant effect on the efficiency of drying. Increasing the air inlet area correspondingly enhanced the performance of the dryer and vice versa.



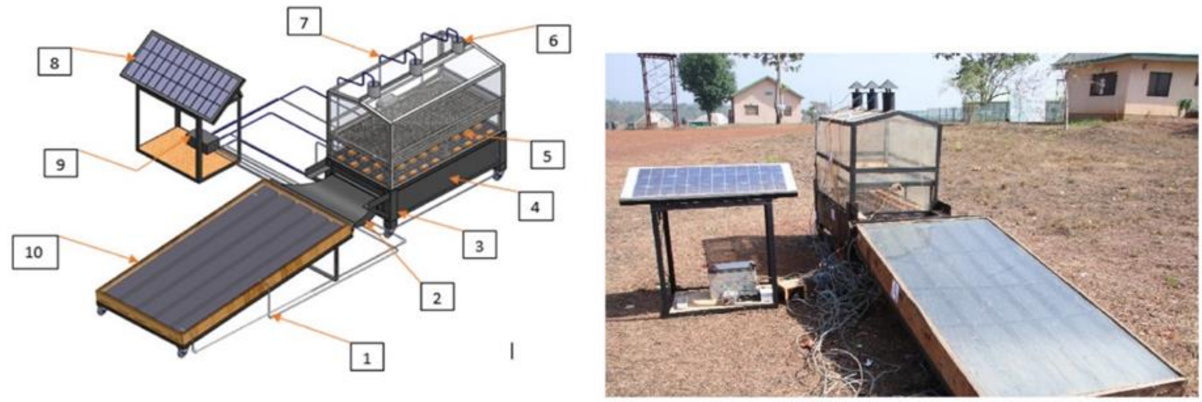
a-Absorbent plate; b-drying tray; c-transparent cover material; d-air inlet area; e-drying chamber door; f-solar panel; g-DC battery; h-drying cabin; i-dryer telescopic leg; j-air outlet; k-blower; l-solar charge controller.

Figure 34. Exploded view of the dryer (Etim *et al.*, 2020).

Figure 35. Aerial view of the experimental set up (Etim *et al.*, 2020).

Komolafe *et al.* (2021) examined forced convective solar drying system for cocoa beans incorporated with thermal energy storage to increase the dryer's operation period (Figure 36). The drying process of cocoa with the developed dryer is a combination of convective heating of the hot air and the direct radiation through the Perspex glass cover. It took 50 h to decrease moisture content from 0.60 to 0.059 g g^{-1} w.b.

Oni *et al.* (2022) compared modern fabricated solar dryer (MFSD) (Figure 37), hybrid biomass dryer (HBD) (Figure 38) and open-air drying (OAD) methods of maize to prevent aflatoxin-contamination. According to the results, a faster drying process with a reduction of aflatoxin in solar dried maize samples were obtained.



1-One of the temperature cables; 2-connecting duct; 3-supporting frame; 4-plenium chamber; 5-drying chamber; 6-chimney; 7-one of the relative humidity sensor; 8-solar panel; 9-data acquisition system; 10-solar collector.

Figure 36. Schematic and pictorial view of the experimental set-up indicating all the major components of forced convective solar dryer (Komolafe *et al*., 2021).

Figure 37. Modern fabricated solar dryer (Oni *et al*., 2022).

Figure 38. Solar biomass dryer (Oni *et al*., 2022).

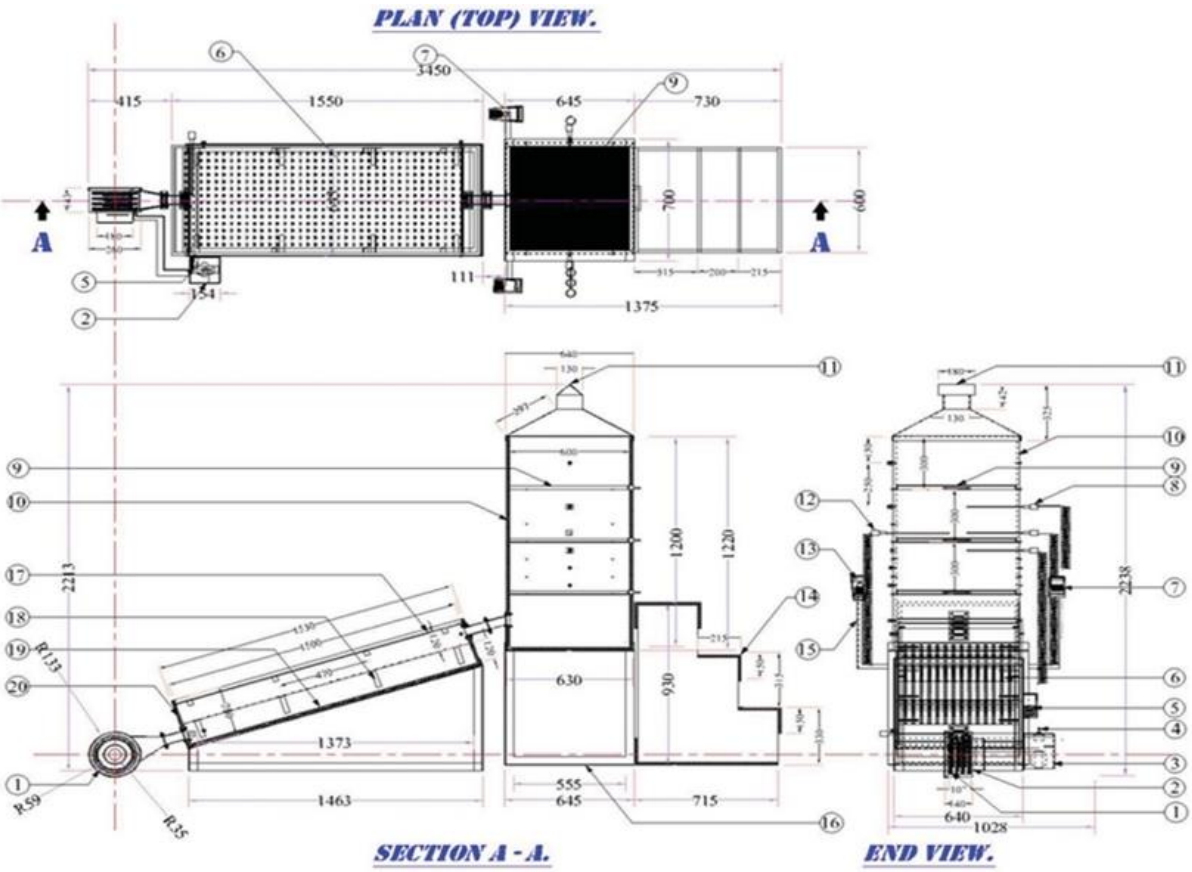
Kuhe *et al.* (2022) developed and tested a mixed-mode active solar crop dryer with a transpired solar air heater and conducted experiments for maize drying (Figure 39 and Figure 40). According to the results, the grain samples are dried faster at higher air mass flow rates. The drying efficiencies ranged between 55.3-82.2%. The drying efficiency reached its highest value at air mass flow rate of 0.038 kg s^{-1} and the minimum value at air mass flow rate of 0.026 kg s^{-1}. The developed system is suitable for drying 6 kg of maize in one batch in six hours.

Figure 39. Complete assembly of the active transpired indirect solar cabinet dryer (Kuhe *et al.* (2022)).

CONCLUSION

In Nigeria, part of the challenges of sustainable food for its citizens is as a result of loss of crop produces to wastage due to inadequate preservation techniques. This challenge had led to the introduction of solar dryers as a preservation appliance in Nigeria over the past few decades. They all could be used for drying different products according to the climatic conditions of Nigeria in the drying industry, they could improve product quality then produced by sun drying.

In as much as the fact that solar drying appliances is not as popular as the traditional open-air sun drying being used, there has been a considerable study carried out those dryers with most documented in leading articles. This article, on the review of most of the research works carried out using solar dryers in drying various crop produce shows that, there is great potential for its usage in Nigeria.



1 Fan, 2 Blower fan housing, 3 Fan regulator casing, 4 Fan Regulator, 5 Solarimeter, 6 Transpired Absorber Plate, 7 Thermocouple, 8 Thermocouple probe, 9 Trays, 10. Drying cabinet, 11 Vent, 12 Air flow probe,13. Air flow metre, 14 Staircase, 15 Probe hanger, 16 Frame, 17 Glass cover, 18 Absorber plate hanger, 19 Insulated lining, 20 Solar box collector.

Figure 40. Detailed drawings of solar dryer (Kuhe *et al.*, 2022).

RECOMMENDATIONS

The research experiments reviewed so far shows great potentials for its application in Nigeria. The government should key into this initiative through establishment of support bodies for the local farmers rather than leaving the cost and its associated expenses in setting up large scale solar dryers to the local farmers. Also, efforts should be made to encourage the commercialization of the solar dryers fabricated using the locally available materials. Lastly, sensitization of the local farmers should be carried out across the country on the benefits associated with using a solar dryer for the drying of their agricultural products over the traditional open sun drying which they are used to over the years.

ACKNOWLEDGEMENT

We would like to acknowledge support of Dr. Kursat Çelik of Akdeniz University during this review work.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Henry Okechukwu Okonkwo: Contributed to literature research, evaluation and writing of the paper
Can Ertekin: Contributed to supervising, evaluation, editing and reviewing of the paper.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1191442

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 430-441

Review Article

Application of Value Engineering to Identify and Solve Irrigation Water Allocation Problems

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ABSTRACT

Periodic assessment and monitoring of the functionality of irrigation scheme components is the popularly known approach for identifying and fixing existing or looming problems. For example the widely used quantitative metrics for irrigation water allocation performance assessment include equity, adequacy, and reliability of water supply. However, a qualitative metric that is seldom applied particularly in Nigeria is the value engineering method. A value engineering method is problem identification and solving approach commonly used to analyze the level of functionality of a given system or its components. The approach comprised the following phases; problem identification, system functionality analysis, creation, evaluation and development of value alternatives. A value engineering approach was applied to identify and solve the water allocation problem at Watari Irrigation Project (WIP), Kano Nigeria. Eleven (11) major problems related to water allocation were identified, and 27 solutions (ideas) were suggested, screened and reduced to 13 by the irrigating management experts. Five (5) value alternatives (VA) from the finally screened ideas were formed by putting 2 or 3 ideas as an integrated solution for a given problem. The 5 value alternatives include repairing water conveyance infrastructures, dredging water conveyance infrastructures, improving on-farm water management, conducting policy dialogue and alteration and creating awareness and sensitization campaigns. After scoring these value alternatives using a scale of 0 to 10 by another set of irrigation experts, dredging water conveyance infrastructures is having the highest score of 8.19 and hence, it requires urgent attention from the relevant authority.

REVIEW ARTICLE

Received: 19.10.2022
Accepted: 05.12.2022

Keywords:

- Irrigation,
- Water allocation,
- Problem identification and solving,
- Value engineering

To cite: Shanono J and Nasidi NM (2022). Application of Value Engineering to Identify and Solve Irrigation Water Allocation Problems. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 430-441.* https://doi.org/10.46592/turkager.1191442

INTRODUCTION

The establishment of irrigation facilities was primarily to supplement rain season crop production to meet the food demand of the population. In line with the same reason, a huge investment has been made to develop irrigation schemes in the northern part of Nigeria (Shanono *et al.*, 2020). Such irrigation facilities were developed to achieve food security, economy and social well-being for the rural communities and the national economy among others (Raghava, *et al.*, 2011; Jubril *et al.*, 2017). However, irrigation schemes in Nigeria have been reported to perform far below their potential (Gorantiwar and Smont, 2005). The major issue attributed to this problem is poor maintenance by both farmers and managers (Cakmak *et al.*, 2009; Shanono *et al.*, 2021a).

The most common irrigation performance evaluation method is the periodic assessment and monitoring of the functionality scheme's components thereby identifying the existing and potential problems affecting the scheme (Cakmak *et al.*, 2009). Conventionally, the water allocation performance of a given irrigation scheme is often determined using a quantitative approach by computing the ratio of the water delivered to the water released at various levels (irrigation efficiencies). Other indicators for assessing water allocation performance include resilience, vulnerability, adequacy, equity and reliability of water supply (Shanono *et al.*, 2012). These water allocation performance indicators depend not only on the water availability for supply but also on reliable water conveyance and control infrastructures, appropriate water allocation methods, competent operators and farmers' level of compliance (Mellah, 2018). Apart from the water allocation performance evaluation criteria including infrastructural, institutional, operational, and participatory are also widely used to assess irrigation scheme performance (Shanono *et al.*, 2015). However, a qualitative approach that requires experts' knowledge and opinion which attracted little attention, especially in Nigeria is the Value Engineering (VE) method.

A value engineering (VE) method is problem identification and solving approach commonly used to analyze the level of functionality of a system, system components, operations, projects or processes. Initially, the approach entails diagnosing the system's problems and proposing solutions as value alternatives. These alternatives can then be adopted and applied by the relevant authorities thereby improving the performance of the system in terms of efficiency, reliability, sustainability, quality, safety, and life cycle costs. According to Atabay and Galipogullari, (2013) the VE is a technique directed toward analyzing the functions of a system or process to determine "best-value", or the best relationship between work and cost. The VE approach of system assessment was first introduced into the construction industry in the early 1960s. Traditionally VE is a value-enhancing tool rather than just a method of cost-cutting (Chen *et al.*, 2013). For example VE on projects can be used to gain not only cost reduction but also time savings, quality improvement etc. Thus VE is an interdisciplinary problem-solving method that focuses on improving the value of the functions required to accomplish the specific goals of a system under study (El-Nashar and Elyamany, 2017; Shanono *et al.*, 2022).

The VE method was used to evaluate and suggest solutions to the problem of inadequate water supply to the downstream farmers in Egypt. Solutions in the form of value alternatives that suggested the use of separate pipes to irrigate some sectors and to use of PVC pipes for field canals were proposed (El-Nashar and Elyamany, 2017). Hence, the VE method entails the identification of the problems affecting a given system, analyzing the state of the functionality of the system, and creating, generating, and evaluating value alternatives (solutions) for solving the identified problems.

Evaluating the current state of an irrigation scheme's components can certainly serve as a valuable step toward understanding the causes and effects of the existing problems. For example, since the inception of the Watari Irrigation Project (WIP) in 1982, the WIP has been declining in terms of water allocation performances at various levels, infrastructural decay, poor maintenance culture, and stakeholder conflicts among others (Shanono *et al.*, 2020; Shanono *et al.*, 2021b). Several approaches to irrigation performance evaluation have been applied to WIP. This approach includes the water allocation method, soil and water quality, operational, infrastructure and participatory (Shanono *et al.*, 2014; Shanono *et al.*, 2015; Nasidi *et al.*, 2016, Sabo *et al.*, 2021, Zakari *et al.*, 2021). None of these studies attempted to apply the VE. An effort toward applying the VE method to identify and solve irrigation water allocation problems can improve the overall performance of the scheme. The finding of this study is expected to generate a new set of information on the water allocation performance and develop a new set of solutions (value alternatives) that could inform relevant decision-makers. When these solutions are deployed as corrective measures, sustainable food production and national food security can be realized.

MATERIALS and METHODS

The step-by-step procedure of value engineering used to identified and solved water allocation problems at Watari Irrigation Project (WIP) comprised the following phases.

Problems identification phase

This phase involves the identification of problems affecting irrigation water allocation in the study location (Watari Irrigation Project WIP, Kano State, Nigeria. The problem identıfication was conducted using site visits, interviews with farmers and questionnaires administered to irrigation managers and operators. Some of the facts generated include previous and latest conditions of the water conveyance and distribution canals, night storage reservoirs (where water is stored at night and used by the farmers during the day), water allocation method used as well as the other water control structures. It is important to note that this phase is the basis for this kind of study as stressed by Shanono *et al.*, (2022).

Functional analysis phase

In this phase, the functional performance of the irrigation scheme components was assessed. This procedure involves analysing what a component shall do (intended function) not how it is doing (current function). The identified functions were analyzed and determined if it requires improvement, renovation or replacement. After the analysis, as many as possible solutions were suggested to serve as room for multiple options that can improve the water allocation performance of WIP.

Creation phase

The alternatives for solving the identified irrigation water allocation problems are created in this phase. This phase involves brainstorming with irrigation scheme managers, experts and other stakeholders to identify new ways to accomplish the optimum operation of the irrigation scheme component under study. It entails exploring the various ways to perform the functions identified in the function analysis phase. It allows the proposing and brainstorming of the existing and alternative methods thereby, developing a list of potential solutions to the problems (ideas).

Evaluation phase

After the brainstorming in the previous phase, the identified ideas for solving the problems were displayed, evaluated and voted and a list of ideas was produced and those with merits were developed into value alternatives using 4 idea-screening steps as provided by El-Nashar and Elyamany (2017). The 4 idea-screening steps include Go and No Go, Champion, Go for It and Trade-off Analysis. The screened ideas were further subjected to another screening based on the performance characteristics of each idea. The selected performance characteristics include water saving, adequate water supply, less cost and easy maintenance.

Value alternatives phase

In the value alternative development phase, the selected ideas were moulded and expanded into workable solutions. Comparison matrix to calculate the weights of evaluation criteria (C). A scale of 0 to 5 was used to express the importance of each evaluation criterion relative to others. The weighing was conducted by irrigation and water management experts. For example, if a score of 5 is assigned to C_2 against C_1, it indicated that C_2 is extremely important compared to C_1. If a score of 0 is assigned to C_{n-1} against C_2 it indicated that both C_{n-1} and C_2 are equally important. If a score of 3 is assigned to the C_n against C_{n-1}, it indicated that evaluation criterion Cn is more important than C_{n-1} by a score of 3 out of 5 as sown in Table 8. Thus, a score of 1, 2, 3, or 4 is assigned to the comparison matrix for in-between values. The assigned weights were summed up for each of the developed value alternatives.

A questionnaire was administered to evaluate the screened value alternative (VA) using evaluation criteria (value alternative scoring). A score between 0 and 10 was assigned against each evaluation criterion. Irrigation experts having great experience were employed to assign these scores. The weights of evaluation criteria were then calculated by dividing evaluation criteria scores by total evaluation criteria scores. For each expert response, the score of each VA was multiplied by the relevant weight of evaluation criteria obtained above. The total score was calculated for each VA and arrived at a VA with the highest score as proposed by El-Nashar and Elyamany (2017).

RESULTS AND DISCUSSION

Problems identification

The problem identification phase led to the identification of many problems found to be affecting water allocation in Watari Irrigation Project (WIP). The two major problems include poor water delivery downstream of the irrigation project and illegal water abstraction by the farmers whose farmlands were initially considered non-irrigable areas (Shanono *et al.*, 2021a). Several problems related to water allocation at WIP were identified and eleven (11) major ones are presented in Table 1.

Table 1. Summary of major identified problems after the site visit and brainstorming.

The case that was investigated	S/No.	Identified Problems
Poor water allocation performance at Watari Irrigation Project (WIP), Kano State, Nigeria	1	Siltation and weed infestation of the main canal
	2	Cracks and breakages of the main canal
	3	Frequent damage to the main canal as it crosses a river
	4	Siltation and weed infestation of the distributary canal
	5	Broken water control gates
	6	Siltation and weed infestation of the night storage reservoir
	7	Inappropriate water allocation method currently use (continuous flow)
	8	Diverting water illegally to places considered non-irrigable
	9	Overirrigation by upstream and midstream farmers
	10	Lack of participation in project maintenance by the farmers
	11	Lack of effective system monitoring and evaluation by the managers

Functional analysis

The function of each component of water conveyance infrastures of WIP was classified as either primary function (the most important function performed by the component) or secondary function (to categorize function as required or unwanted). The required functions are essential to support the performance of the irrigation project in terms of water allocation whereas the unwanted functions are the negative ones caused by the method used to operate the scheme. The results obtained from the functional analysis of the problem at hand was conducted summarised as shown in Table 2.

Table 2: Functional analysis and classification of irrigation water allocation structures.

Item	Functions	Primary Functions	Secondary Functions	
			Required	Unwanted
The cross-section area of the main canal	Convey the required volume of water to the distributary canals	√		
The cross-section area of the distributary canal	Distribute the required volume of water to the field channels	√		
The cross-section area of filed channels	Deliver water to the farm plots to be used by the farmers	√		
Unlined canals	Cause seepage			√
Climate change	Cause high evaporation rate			√
Water flow control gates	Control the amount of water diverted		√	
İmprovised water flow control gates	Replacing the damaged ones		√	
Water allocation method	The rule for sharing water among farmers		√	
Currently adopted water allocation method/strategy	Cause over-irrigation by farmers			√
Water application method	Scheduling when and how much to irrigate		√	
Surface flow (water conveyance method))	Poor irrigation efficiency, water wastage			√
Monitoring and evaluation strategy	Checking if the water-sharing rules are followed		√	
Participatory irrigation management	Commitment from all stakeholders toward project maintenance		√	
Conflict among stakeholders and conflict resolution	Fighting among stakeholders (farmers, managers, herdsmen etc)			√

Creation of ideas

After brainstorming with WIP managers, irrigation experts and other stakeholders, twenty-seven (27) ideas were generated. The generated ideas were coded and tabulated as shown in Table 3.

Table 3. Summary of generated ideas after brainstorming.

Code	Ideas
Id_1	Construct another main canal
Id_2	Repair/lining the main canal with concrete
Id_3	Dredge the main canal to remove silt and weeds
Id_4	Repair broken main canal where it crosses a river
Id_5	Construct a new canal to bypass the river
Id_6	Construct another water distributory canal
Id_7	Lining the surface of the distributary canal with concrete
Id_8	Dredge the distributary canal to remove silt and weeds
Id_9	Increase water discharge at the canal intake
Id_{10}	Redirect drainage water to irrigate
Id_{11}	Use PVC pipes to convey water to the farm plots
Id_{12}	Adopt in situ water conservation methods downstream
Id_{13}	Use tanks (trucks to convey water to downstream farmers
Id_{14}	Use separate pipes to convey water to downstream farmers
Id_{15}	Dig wash bore wells at downstream as an alternative source of water
Id_{16}	Replace high- with low-water consumptive use crops
Id_{17}	Use effective control gates/valves at each farm to control water use
Id_{18}	Use modern irrigation methods with high water use efficiency
Id_{19}	Abandon some farm plots the downstream
Id_{20}	Repair or replace the damaged water control gates
Id_{21}	Dredge the night storage reservoir to remove silt and weeds
Id_{22}	Change the water allocation method to rotational
Id_{23}	Enlighten upstream farmers on the risk of over-irrigation
Id_{24}	Punish or penalize those diverting water illegally
Id_{25}	Encourage dialogue and participatory irrigation management
Id_{26}	Increase water price
Id_{27}	Develop and deploy an effective monitoring strategy

Evaluation of ideas

The results obtained from the evaluation procedure were presented according to the 4 idea-screening steps as follows.

Step I: Go or No Go - The outcome is based on whether an idea is practicable (Go) or not (No Go) and was suggested by the group of experts as presented in Table 4.

Step II: Champion - The practicable ideas in step I (Go) was further thought of by the experts and decided if it is workable within time and resource limitations thereby supporting (Yes) or rejecting (No). After the screening in Steps I and II, the 27 initially generated ideas were reduced to 15 as presented in Table 4.

Table 4. Go or No Go and Champion evaluation criteria.

Code	Ideas	Go or No Go	Champion
Id_1	Construct another main canal	Go	No
Id_2	Repair/lining the main canal with concrete	Go	Yes
Id_3	Dredge the main canal to remove silt and weeds	Go	Yes
Id_4	Repair broken main canal where it crosses a river	Go	Yes
Id_5	Construct a new canal to bypass the river	Go	No
Id_6	Construct other water distributary canals	No Go	
Id_7	Lining the surface of the distributary canal with concrete	No Go	No
Id_8	Dredge the distributary canal to remove silt and weeds	Go	Yes
Id_9	Increase water discharge at the canal intake	Go	No
Id_{10}	Redirect drainage water to irrigate	Go	No
Id_{11}	Use PVC pipes to convey water to the farm plots	Go	Yes
Id_{12}	Adopt in situ water conservation methods downstream	Go	Yes
Id_{13}	Use tanks (trucks to convey water to downstream farmers	No Go	
Id_{14}	Use separate pipes to convey water to downstream farmers	No Go	
Id_{15}	Dig wash bore wells at downstream as an alternative source of water	Go	No
Id_{16}	Replace high- with low-water consumptive use crops	Go	No
Id_{17}	Use effective control gates/valves at each farm plot	Go	Yes
Id_{18}	Use modern irrigation methods with high water use efficiency	Go	No
Id_{19}	Abandon some farmlands the downstream	No Go	
Id_{20}	Repair or replace the damaged water control gates	Go	Yes
Id_{21}	Dredge the night storage reservoir to remove silt and weeds	Go	Yes
Id_{22}	Change the water allocation method to rotational	Go	Yes
Id_{23}	Enlighten upstream farmers on the risk of over-irrigation	Go	Yes
Id_{24}	Punish/penalize those diverting water illegally	Go	Yes
Id_{25}	Encourage dialogue and participatory irrigation management	Go	Yes
Id_{26}	Increase water price	Go	Yes
Id_{27}	Develop and deploy an effective monitoring strategy	Go	Yes

Step III: Go for it - In this step, the pros and cons of each accepted idea were extensively discussed and debated if it has any advantages and disadvantages and takes the average voting. The 15 screened ideas were further reduced to 14 as summarised in Table 5.

Table 5. Classification of the screened ideas as advantages or disadvantages and vote for the acceptance of the idea.

Code	Ideas	Advantages	Disadvantages	Average Vote
Id_2	Repair/lining the main canal with concrete	a. Reduce seepage losses b. Minimize friction losses c. Increase the velocity of flows	High cost of construction	Accept
Id_3	Dredge the main canal to remove silt and weeds	a. Increase carrying capacity b. Increase the velocity of flows		Accept
Id_4	Repair broken main canal where it crosses a river	a. Decrease overflows b. Reduce losses by seepage	High cost of construction	Accept
Id_8	Dredge the distributary canal to remove silt and weeds	c. Increase carrying capacity d. Increase the velocity of flows	High cost	Accept
Id_{10}	Use PVC pipes to convey water to the farm plots	a. Reduce seepage losses b. Minimize friction losses c. Increase the velocity of flows	High cost	Accept
Id_{11}	Adopt in situ water conservation methods downstream	a. Require little effort b. Low cost		Accept
Id_{16}	Use effective control gates/valves at each farm plot	a. Control water use in each farm b. Record water use in each farm		Accept
Id_{20}	Repair or replace the damaged water control gates	a. Control water use in each farm b. Record water use in each farm		Accept
Id_{21}	Dredge the night storage reservoir to remove silt and weeds	a. Store more water b. Reduce water shortage risk	High cost	Accept
Id_{22}	Change the water allocation method to rotational	a. In rotational, farmers can irrigate only when they are scheduled		Accept
Id_{23}	Enlighten upstream farmers on the risk of over-irrigation	a. Farmers can understand too much water application can adversely affect yield		Accept
Id_{24}	Punish or penalize those diverting water illegally	a. Enforce adherence to laws	This may lead to conflicts	**Reject**
Id_{25}	Encourage dialogue and participatory irrigation management	a. Achieve adherence to laws through dialogue b. All stakeholders to have ownership and feel responsible		Accept
Id_{26}	Increase water price	a. Farmers can opt to reduce costs by regulating irrigation		Accept
Id_{27}	Develop and deploy an effective monitoring strategy	a. Enforce adherence to laws	This may lead to misunderstanding	Accept

Step IV: Trade-off study – After a long and extensive deliberation with irrigation water management experts, the final alternatives to solve the identified and screened water allocation problems in the Watari Irrigation Project were selected. These alternatives were considered based on the performance characteristics of each idea. The selected performance characteristics include water saving, adequate water supply, less cost and easy maintenance. The idea Id_{10} was removed because it will consume a huge amount of money. The 14 screened ideas were further reduced to 13 as summarised in Table 6.

Table 6. Trade-off analysis of the performance characteristics of an idea to select the final alternatives to solve irrigation water allocation problems at WIP.

Code	Ideas	Performance Indicators				Voting
		Save water	Less cost	Adequate supply	Easy maintenance	
Id_2	Repair/lining the main canal with concrete	√		√	√	Accept
Id_3	Dredge the main canal to remove silt and weeds	√	√	√	√	Accept
Id_4	Repair broken main canal where it crosses a river	√		√	√	Accept
Id_8	Dredge the distributary canal to remove silt and weeds	√	√	√	√	Accept
Id_{10}	Use PVC pipes to convey water to the farm plots	√		√	√	**Reject**
Id_{11}	Adopt in situ water conservation downstream	√	√	√	√	Accept
Id_{16}	Use effective control gates/valves at each farm plot	√		√	√	Accept
Id_{20}	Repair or replace the damaged water control gates	√	√	√	√	Accept
Id_{21}	Dredge the night storage reservoir to remove silt and weeds	√		√	√	Accept
Id_{22}	Change the water allocation method to rotational	√	√	√	√	Accept
Id_{23}	Enlighten upstream farmers on the risk of over-irrigation	√	√	√	√	Accept
Id_{25}	Encourage dialogue & participatory irrigation management	√	√	√	√	Accept
Id_{26}	Increase water price	√	√	√	√	Accept
Id_{27}	Develop and deploy an effective monitoring strategy	√	√	√	√	Accept

Value alternatives development

Five (5) value alternatives (VA) from the thirteen (13) finally screened ideas were formed by putting 2 or 3 ideas as an integrated solution for a given integrated problem. Thus, the 13 screened problems were merged to form 5 value alternatives as summarized in Table 7.

Table 7. Value alternatives for solving the identified problems affecting the performance of irrigation water allocation problems at WIP.

Value Alternatives (VA)	Group of Ideas
VA_1 (Repair water conveyance infrastructures)	Id_2, Id_4 and Id_{20}
VA_2 (Dredge water conveyance infrastructures)	Id_3, Id_8 and Id_{21}
VA_3 (Improve on-farm water management)	Id_{11} and Id_{16}
VA_4 (Conduct policy dialogue and alteration)	Id_{22}, Id_{25} and Id_{27}
VA_5 (Create awareness and sensitization campaign)	Id_{23} and Id_{26}

Comparison matrix was used to assign weight in-between values and calculate the weights of evaluation criteria (C) as summarised in Table 8.

Table 8. Comparison matrix for weighing the evaluation criteria (C).

Evaluation criteria (C)		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Adequacy of supply (C_1)	C_1		C_2 / 3	C_3 / 2	C_1 / 4	C_5 / 4	C_6 / 3	C_1 / 3	C_8 / 2
Durability (C_2)	C_2			C_2 / 3	C_2 / 2	C_5 / 1	C_6 / 2	C_2 / 1	C_2 / 3
Maintainability (C_3)	C_3				C_3 / 3	C_3 / 2	C_3 / 1	C_7 / 3	C_8 / 1
Constructability (C_4)	C_4					C_4 / 1	C_4 / 1	C_7 / 4	C_4 / 2
Sustainability (C_5)	C_5						C_6 / 2	C_5 / 3	C_5 / 2
Environmental impact (C_6)	C_6							C_7 / 2	C_8 / 2
Water saving (C_7)	C_7								C_8 / 1
Safety and health (C_8)	C_8								

The assigned weights were summed up for each of the developed value alternatives as summarised in Table 9.

Table 9. Weight of evaluation criteria and value alternative score.

Evaluation criteria (C)	Weight	VA_1	VA_2	VA_3	VA_4	VA_5
Adequacy of supply (C_1)	0.11	9	9	9	7	7
Durability (C_2)	0.19	7	9	5	4	5
Maintainability (C_3)	0.13	4	8	7	6	7
Constructability (C_4)	0.06	7	7	8	5	4
Sustainability (C_5)	0.16	8	9	8	9	9
Environmental impact (C_6)	0.11	6	7	7	8	7
Water saving (C_7)	0.14	9	8	9	9	9
Safety and health (C_8)	0.10	7	7	7	6	9
Total	**1.00**	**57**	**64**	**60**	**54**	**57**

Value alternative scoring

After scoring the value alternative by multiplying the each weight by the corresponding score, the total score was calculated for each VA and arrived at a VA with the highest score as shown in Table 10. Second value alternative (VA2): dredging water conveyance infrastructures was found to have the highest score of 8.19 as it requires less cost, can be done within short period and hence, it requires urgent attention from the WIP authority. This results is not in line with the solution offered by the El-Nashar and Elyamany (2017) who suggested the use of separate PVC pipes to irrigation bramch of the irrigation scheme.

Table 10. Scores of value alternative.

Evaluation criteria (C)	Weight	VA_1	VA_2	VA_3	VA_4	VA_5
Adequacy of supply (C_1)	0.11	0.99	0.99	0.99	0.77	0.77
Durability (C_2)	0.19	1.33	1.71	0.95	0.76	0.95
Maintainability (C_3)	0.13	0.52	1.04	0.91	0.78	0.91
Constructability (C_4)	0.06	0.42	0.42	0.48	0.30	0.24
Sustainability (C_5)	0.16	1.28	1.44	1.28	1.44	1.44
Environmental impact (C_6)	0.11	0.66	0.77	0.77	0.88	0.77
Water saving (C_7)	0.14	1.26	1.12	1.26	1.26	1.26
Safety and health (C_8)	0.10	0.70	0.70	0.70	0.60	0.90
Total	**1.00**	**7.16**	**8.19**	**7.34**	**6.79**	**7.24**

CONCLUSION

The existing water allocation problems known to adversely affect the performance of Watari Irrigation Project (WIP), Kano Nigeria were identified, analyzed and solutions were also suggested using value engineering approach. Primarily, two major problems were identified which include inadequate water supply downstream of the irrigation project and unauthorized water abstraction by the farmers. These two problems are as a results of many other problems related to water allocation at WIP and this study identified and selected eleven (11) major ones. Afterwhich, functional analysis of the major water conveyance infrastructures was conducted through an extensive brainstorming. Twenty seven (27) solutions (ideas) to these 11 problems were suggested (the creation phase). The 27 proposed solutions were subjected to screening by the water and irrigation management experts and reduced to 13 (the evaluation phase). Five (5) value alternatives (VA) from the finally 13 screened ideas were formed by putting 2 or 3 ideas as an integrated solution for a given problem. The 5 value alternatives include repairing water conveyance infrastructures, dredging water conveyance infrastructures, improving on-farm water management, conducting policy dialogue and alteration and creating awareness and sensitization campaigns. After scoring these value alternatives using a scale of 0 to 10 by another set of irrigation and water management experts, dredging water conveyance infrastructures is having the highest score of 8.19 as it requires less cost, can be done within short period and hence, it requires urgent attention from the WIP authority. Thus, value engineering method can be said to be a good system problem identification, analizing and solving tool. It guides in finding optimum solutions by focusing not only the basic function of the system but also economic and time constraints.

DECLARATION OF COMPETING INTEREST

The authors declare that he has no conflict of interests.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors are responsible for all parts of this article (all of them participated in aspects of the article).
Nura Jafar Shanono: Investigation, conceptualization, methodology, formal analysis, data curation, writing-original draft, review, and editing, visualization.
Nuraddeen Mukhtar Nasidi: Investigation, methodology, formal analysis, validation, review, and editing, visualization.

ETHICS COMMITTE DECISION

This article does not require an Ethics Committee Decision.

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Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.2021.v02i02.016

Turk J Agr Eng Res
(TURKAGER)
e-ISSN: 2717-8420
2021, 2(2): 434-449

Research Article

Optimization of Mechanical Oil Expression from Sandbox (*Hura crepitans* Linn.) Seeds

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ABSTRACT

Optimization of process variables has become very vital in oil extraction processes to obtain maximum oil yield from oilseeds and nuts. This work focussed on the optimization of process oil extraction process from sandbox seed by mechanical expression. Effects of moisture content, roasting temperature, roasting time, expression pressure and expression time on oil yield from sandbox seed was studied using a 5×5 Central Composite Rotatable Design of Response Surface Methodology experimental design. Results obtained were subjected to Analysis of Variance (ANOVA) and SPSS statistical tool at (p = 0.05). Optimum conditions predicted were validated by experiments. All the processing factors were significant at ($p = 0.05$) for the sandbox oil yield except roasting temperature. The experimental results and predicted values showed low deviation (0.01-0.62). Oil yields obtained from the sandbox seed at varying process conditions varied from 16.38-38.68%. The maximum oil yield of 38.68% was obtained when the sandbox seed was subjected to process conditions of 6% moisture content, 85°C roasting temperature, 15 min roasting time, expression pressure of 20 MPa and 8 min pressing time. Mathematical equations to predict sandbox seed oil yield at varying process conditions were developed with an R^2 (0.8908). The optimum extractable oil yield of 38.95% was predicted for sandbox seed at processing conditions of 7.03% moisture content, 97.72°C roasting temperature, 11.32 min roasting time, 15.11 MPa expression pressure and 8.57 min expression time. The study results provide data for designs of process and equipment for oil extraction from sandbox and other oilseeds.

RESEARCH ARTICLE

Received: 03.10.2021
Accepted: 08.12.2021

Keywords:

- Process optimization,
- Sandbox seed,
- Oil extraction,
- Mechanical expression

To cite: Onwe, DN, Bamgboye AI (2021). Optimization of Mechanical Oil Expression from Sandbox (*Hura crepitans* Linn.) Seeds. Turkish Journal of Agricultural Engineering Research (TURKAGER), 2(2): 434-449. *https://doi.org/10.46592/turkager.2021.v02i02.016*

INTRODUCTION

The sandbox (*Hura crepitans* Linn.) tree is of the (Euphorbiaceae) family, indigenous to the humid zones of the American continents. The sandbox is referred to as the dynamite tree because of the shooting reverberations of the matured pods as they split before dropping. The sandbox seeds are flattened, about 2 cm, arranged as carpel of 14-16 seeds in fruit capsules of height 3-5 cm and diameter of 5-8 cm (Feldkamp, 2006; Okolie *et al.,* 2012). Consumption of sandbox seed has been reported to cause sicknesses such as burning throat, suffocation, headache, nausea, stomach pain, vomiting and diarrhea, while the plant sap coming in contact with the eye can cause blindness. Sandbox leaves have been recognized to be used as curatives, but the seed has not really been harnessed and used (Allen, 2000; Clarke, 2000). Sandbox seed has been noted to contain a number of important properties that can be useful for the production of feeds, paints, and cosmetics amongst others (Olatidoye *et al.,* 2010; Idowu *et al.,* 2012). Sandbox seed was noted amongst seeds with high oil content (Idowu *et al.,* 2012; Basumatary, 2013). Sandbox seed properties, proximate composition and its oil's chemical characterization have been studied (Fowomola and Akindahunsi, 2007; Idowu *et al.,* 2012; Okolie et al., 2012). However, sandbox has been classified amongst underutilized species of plants; in most parts of the world, the trees have been used as shade due to their large spreading branches (Idowu *et al.,* 2012). In Nigeria, the trees are grown as cover plants, while the seeds were thrown away as waste (Adewuyi *et al.,* 2012).

Oil extraction from sandbox seeds by earlier studies was focused mainly on solvent extraction (Okolie *et al.,* 2012; Muhammed *et al.,* 2013; Adewuyi *et al.,* 2014; Nwanorh, 2015; Ottih *et al.,* 2015; Shonekan and Ajayi, 2015). Oil extraction by solvent methods has increased oil recovery up to 98% and has made it economically attractive for some oilseeds (Matthäus, 2012). However, oil extraction by mechanical methods still remains a good option for oil extraction from seeds and nuts.

Mechanical oil expression from many agricultural products has been studied, viz: almond seed (Akubude *et al.,* 2017); groundnut (Pominski *et al.,* 1970; Adeeko and Ajibola, 1990; Olajide *et al.,* 2014); dika kernels (Abidakun *et al.,* 2012; Ogunsina *et al.,* 2014); African oil bean (Aremu and Ogunlade, 2016); various clones of rubber seed (Ebewele *et al.,* 2010); fine and coarse roselle seed (Bamgboye and Adejumo, 2011); sesame seeds (Tunde-Akintunde *et al.,* 2000; Akinoso *et al.,* 2006; Hashim *et al.,* 2014; Elkhaleefa and Shigidi, 2015); soybean seed (Mwithiga and Moriasi, 2007; Lawson *et al.,* 2010); bitter gourd (Umamaheshwari and Dinesh Sankar Reddy, 2016); neem seed (Awolu *et al.,* 2013; Orhevba *et al.,* 2013); avocado fruit (Southwell and Haris, 1990); rice bran respectively (Sivala *et al.,* 1991); coconut (Hammonds *et al.,* 1991); shea butter (Olaniyan and Oje, 2007); melon (Ajibola *et al.,* 1990); conophor nuts (Fasina and Ajibola, 1989); peanut (Badwaik *et al.,* 2012); sunflower kernels (Southwell and Harris, 1992); African star apple seed (Ajala and Adeleke, 2014); *Moringa* seed (Adejumo *et al.,* 2013; Fakayode and Ajav, 2016).

According to Mwithiga and Moriasi (2007), seed quality is the first determinant of the quantity and quality of producible oil from an oilseed, before the consideration of the process and machine to be used. Variations in seed and machine parameters including seed size, moisture level, preparation temperature and time, expression pressure and duration of extraction greatly influence oil yields from oilseeds and nuts during mechanical expression

(Khan and Hanna, 1984). It is therefore of optimum importance to control these parameters during oil extraction for optimal oil extraction. Improper management of these variables during mechanical expression may possibly lead to low oil yield and oil quality. Therefore, quality lipid feedstocks and effective handing before expression are vital to achieving quality and higher oil yield (Bamgboye and Adejumo, 2011).

Data for mechanical oil extraction from sandbox seed and process optimization of same is however scarce. To quantify and predict oil yield from sandbox seed by mechanical expression relatively to process factors, the Response Surface Methodology (RSM) was employed. According to Giwa *et al.* (2015), process optimization where other process factors are kept constant and varying one, does not correctly capture the inter-relationship existing amongst the factors. Hence, such procedure may not accurately predict the best combination of interaction of factors that gives the optimum outcome of the process. The (RSM) was developed as an appropriate statistical tool for optimization of processes. It employs the use of Central Composite Design (CCD), Box-Behnken design and D-optimal experimental designs (Triveni *et al.*, 2001). According to Hamzat and Clarke (1993), accurate knowledge of interactions between oil expression devices and processing variables improves the efficiency of oil extraction. RSM has shown to be a tool in effectively relate the inter-relationship occurring amongst process variables such as effect of moisture, heat application and heating time, pressing pressure and duration on oil yield. Superior to normal methods, the RSM uses minimal experimental investigations to predict the values of process factor combination for optimum result(s) and also generates model equation(s) connecting the factors and response(s) (Giwa *et al.*, 2015). RSM utilizes results from practical experiments to generate models that can predict response such as oil yield in relation to process factors. In this work, how process factors: moisture content, treating temperature and time, expression pressure and time influence oil expression and yield from sandbox seed was investigated and optimized using the RSM.

MATERIALS AND METHODS

Design of experimental

Among processing factors, seed moisture, treating temperature and time, expression pressure and time have been observed to significantly at (p = 0.05) increase oil yield by mechanical expression methods (Fakayode and Ajav, 2016). The process of oil extraction from sandbox seed by mechanical means was optimized by varying these factors. The design of experiment adopted was 5×5 factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology developed by Box *et al.* (1978). According to Fakayode and Ajav (2016), CCRD is combining factorial, (d_f), axial, (d_a) and central, (d_c) design points respectively. $t = 2^c(d_f) + 2c(d_a) + c(d_c)$, represents the total number of treatments, where 'c' is the number of process factors. The average experiment of the CCRD design was 32 combinations, representing $T = 2^{c-1} + 2c + (t_0)$ design points, consisting of 16 factorial CCD, 10 axial points and 6 replications of the center points.

The initial moisture content of the mature sandbox seed influenced the decision of the moisture content range selected for the experiment. There is a lack of information on mechanical extraction of oil from sandbox seed, its oil yield and optimization of the process. Thus, data from previous studies on oil extraction by mechanical methods from other oilseeds was used to carry out preliminary investigations on the sandbox seed. Results obtained informed the varying values of process factors selected for the experiment. Values used were; moisture content, mc (4, 6, 8, 10 and 12% wet-basis); roasting temperature, γ_{tp} (80, 85, 90, 95 and 100^{o}C) and time, γ_{tm} (0, 5, 10, 15 and 20 min); expression pressure, ε_{Pr} (5, 10, 15, 20 and 25 MPa) and time, εx_{tm} (2, 4, 6, 8 and 10 min).

Development of laboratory screw press

A five-barrel pilot screw press (Figure 1) was developed and used for the experiment. Designed for 25MPa maximum capacity, the screw pitch diameter was calibrated by length to vary the applied pressure. Preliminary test was conducted by placing a piece of wire gauze into the base of the screw press barrel, and 500 gram sample of the ground sandbox was placed on the wire gauze and another piece of wire gauze was placed on the specimen. The 25 MPa mark was got with a spring gauge as a point where the press screw could not push the sample any further. Pitch lengths were used to mark the other pressure points; 20, 15, 10 and 5 MPa respectively. The multiple barrel press designed was adopted to easily cover the multiple experiments carried out.

Preparation of sample

About 100 kg of mature sandbox fruits were collected from under the trees in Uyo metropolis, Akwa Ibom State, Nigeria between 2106-2018. The fruits (Figure 2) were cracked to remove the seeds (Figure 3) and the seeds peeled to get the kernel (mesocarp) (Figure 4).

Figure 1. Screw press.

Figure 2. Sandbox fruits.

Figure 3. Sandbox seeds.

Figure 4. Sandbox kernels.

Moisture content determination

Initial moisture content of the sandbox seeds was determined using ASABE standard for oven drying method as adopted by Olaoye (2000), Ozguven and Vursavus (2005), Fakayode and Ajav (2016) and Onwe *et al.* (2020) for castor nut, pine nuts, African star apple and

Moringa seeds respectively. Three 50 g ground samples of the sandbox box seed designated A, B, C were used for the experiment. The three different samples were placed and dried in the oven at 105°C and weighed after 6 hours and subsequently at intervals until a constant weight was attained. Equation 1 below was used to calculate the mc (wet-basis).

$$MC\ (\%\ w.b.) = \frac{W_i - W_f}{W_i} \times 100 \qquad (1)$$

W_i = initial sample weight and W_f = final sample weight

1 kg each of the samples were subjected to 4, 6, 8, 10 and 12% wet basis moisture content respectively using Equation 2 as adopted by Olajide (2000); Fakayode and Ajav (2016).

$$Q = \left(\frac{100 - S_i}{100 - S_d} - 1\right) \times W_s \qquad (2)$$

Q = quantity of required moisture to be absorbed (ml); S_i = initial sample moisture (%wb); S_d = required sample moisture (%wb); W_s = weight of sample (g)
The conditioned samples were wrapped in fabrics and placed in polyethylene bags and stored in a refrigerator at 5°C for two days for the required moisture content to even up.

After that, the samples were stored in a desiccator to retain them at the conditioned moisture content for the experiment.

Experimental procedures

From the already conditioned samples of the sandbox seed at 4, 6. 8, 10, 12% wb moisture content, the various experiments were conducted using 500 g weight. A hotplate was used for roasting the sandbox seed samples. The various roasting temperature levels of 80, 85, 90, 95 and 100°C were achieved by regulating the hotplate temperature. A frying pot was placed on top of the hotplate, and a digital thermometer probe was used to check the pot temperature until the required temperatures were obtained before pouring the sandbox seed samples for frying. A stopwatch was used to time the roasting periods for 0, 5, 10, 15 and 20 min respectively. Afterwards, the samples were fed into the extraction chamber (barrel); wire gauze was placed at the base of the barrel and on top of the samples before pressing. The samples were subjected to 5, 10, 15, 20 and 25 MPa extraction pressure, at 2, 4, 6, 8 and 10 min extraction duration. The experiments were replicated three times. Pressed samples were left to drain into containers for three days before the weight of the oil was determined (Weiss, 2000). Oil yields were determined by Equation 3, used by Bello and Daniel, (2015) for groundnut oil yield determination.

$$Oil\ Yield\ (\%) = \frac{Wieght\ of\ oil\ expressed}{Wieght\ of\ sandbox\ seed\ sample\ before\ pressing} \times 100 \qquad (3)$$

Response Surface Methodology (RSM)

The experiment was designed using a software package of RSM Design Expert (6.0.6). The software generated sets of combinations of experimental factors when their ranges were keyed in. These combinations of factors were used for the experiments. The oil expressions were carried out using these combinations. The percentage of expressed oil for each experiment was keyed in as the response of the particular combination. The Design Expert contains four different models, which include the linear, the two factorial interactions (2FI), the quadratic and the cubic models respectively. These four models analyses the outcome of the experiments in terms of the probability of error value (p-value) and coefficient of determination (R^2), which are statistical parameters indicating the degree of relationship between process factors and oil yield. The decision on the best model for the oil expression process was based on their p and R^2 values. The chosen model was subjected to Analysis Of Variance (ANOVA) to further prove the model's level of significance and fitness in explaining the relationship between the process factors and oil yield. Then the tests of between-subjects of effects of processing conditions on oil yield were analyzed using Windows 20.0 SPSS statistical software package. Combination conditions suggested to be optimal for oil expression by the model were used to conduct fresh experiments for validation. Then, the results from real experimental and model predicted values were also compared to test for similarities.

RESULTS AND DISCUSSION

The moisture content of 6.12% wb was obtained as the initial moisture content of the sandbox seed. The oil yields from the combination of varying process conditions are as shown in Table 1. Plots relating the process factors and the oil yield are presented in Figures. 5-9. The sandbox oil yield varied from 16.38-38.68%. The optimum oil yield of 38.68% was obtained when the sandbox seed was subjected to process conditions of 6% moisture content, 85°C roasting temperature, 15 min roasting time, expression pressure of 20 MPa and 8 min pressing time. Relatively to sandbox seed oil extraction by solvent methods; Ottih *et al.* (2015) and Okolie *et al.* (2012) obtained 57.26% and 53.61% oil yield respectively using n-hexane. Nwanorh (2015) obtained 42.70% oil yield using petroleum ether. According to Bockisch (1998), the reason why solvent extraction produces better oil yield when compared to other extraction methods could be as a result of solvents permeation ability to solubilize lipids in the cell structures to extract as much oil as possible. However, Adewuyi *et al.* (2014) and Shonekan and Ajayi (2015) obtained 37.75 and 36.70% oil yield respectively using n-hexane. Difference in oil yield during extraction is a function of extraction methods employed, and also biological and environmental conditions (Anwar *et al.*, 2006; Orhevba *et al.*, 2013).

Table 1. Oil yield from sandbox seed at various processing conditions.

Run	Factor 1 A: mc (%)	Factor 2 B: γ_{tp} (%)	Factor 3 C: γ_{tm} (min)	Factor 4 D: ε_{Pr} (MPa)	Factor 5 E: εx_{tm} (min)	Response Oil yield (%)
1	8	90	10	15	6	36.14
2	6	85	5	10	8	32.77
3	6	95	15	10	8	35.09
4	10	95	15	10	4	23.66
5	8	90	10	15	2	16.38
6	8	90	10	15	6	35.00
7	10	85	15	20	4	24.43
8	8	90	10	15	10	37.02
9	8	80	10	15	6	32.66
10	4	90	10	15	6	32.22
11	8	90	10	15	6	36.22
12	6	85	15	10	4	24.68
13	8	90	10	15	6	35.00
14	10	95	5	20	4	19.44
15	10	85	5	20	8	25.00
16	8	100	10	15	6	36.00
17	6	95	15	20	4	25.00
18	6	95	5	10	4	21.66
19	8	90	20	15	6	34.33
20	8	90	10	15	6	36.77
21	10	95	15	20	8	32.88
22	8	90	10	5	6	18.66
23	8	90	10	25	6	30.00
24	12	90	10	15	6	20.49
25	6	95	5	20	8	30.66
26	10	85	5	10	4	24.99
27	8	90	10	15	6	35.66
28	8	90	0	15	6	18.62
29	10	95	5	10	8	32.54
30	10	85	15	10	8	34.65
31	6	85	15	20	8	38.68
32	6	85	5	20	4	23.11

Where mc = moisture content of sandbox seed, γ_{tp} = Roasting temperature, γ_{tm} = Roasting time, ε_{Pr} = Expression pressure and εx_{tm} = Extraction time

The oil recovery from the sandbox seed increased substantially at the moisture content range of 4-8% wb, but declined when the moisture level exceeded 8% wb (Figures 5-6). This could be attributed to the observation by Sivala *et al.* (1992), that moisture addition pushes particles faster to saturation points during oil expression. Nevertheless, in the presence of excess moisture, the particle's liquid phase absorbs the expression pressure and debar it from reaching the oil capillaries, thereby, decreasing oil yield.

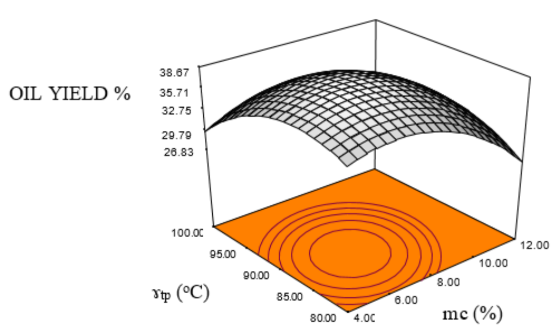

Figure 5. Extraction time and moisture content against oil yield.

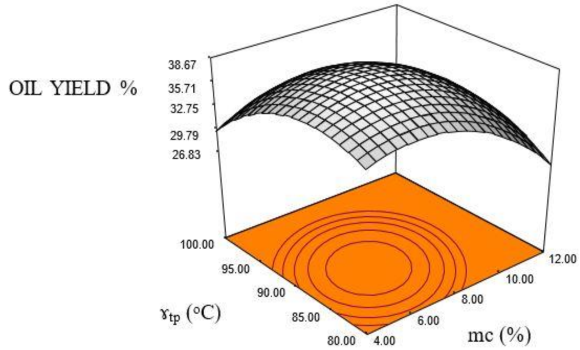

Figure 6. Roasting temperature and moisture content against oil yield.

The highest oil yield was obtained for sandbox seed at the moisture level of 8% wb (Figures 5-6). The trend agrees to earlier results from groundnut, neem, avocado, roselle, dika and locust beans (Southwell *et al.*, 1990; Owolarafe *et al.*, 2003; Ogunsina *et al.*, 2008; Bamgboye and Adejumo, 2011; Orhevba *et al.*, 2013; Olajide *et al.*, 2014) and many other authors as the most suitable moisture level for mechanical oil extraction.
Increase in the sandbox box oil yield was observed as the roasting temperature increased from 80-90°C. The oil yield decreases as the roasting temperature increased from 90-100°C (Figs. 6-7). Roasting temperature has been recognized as one of the factors that greatly enhance oil yield (Costa *et al.*, 2014; Terigar *et al.*, 2011; Martinez *et al.*, 2013). According to Fakayode and Ajav, (2016), expected oil yield cannot be got from oil samples at lower heating temperatures. At the same time, roasting at high temperatures hardens oil samples, causing them to resist applied pressure during extraction, and thus, leading to lower oil yield. In comparison, the roasting temperature value for maximum oil recovery from sandbox seed was similar to 81.93°C heating temperature reported by Olajide, (2000) for groundnut kernel (*Arachis hypogeae*), 90°C reported by Aremu and Ogunlade, (2016) for African oil bean seed. The sandbox seed grain is very soft and roasting at 90°C was suitable heat treatment to release optimum oil yield from it.

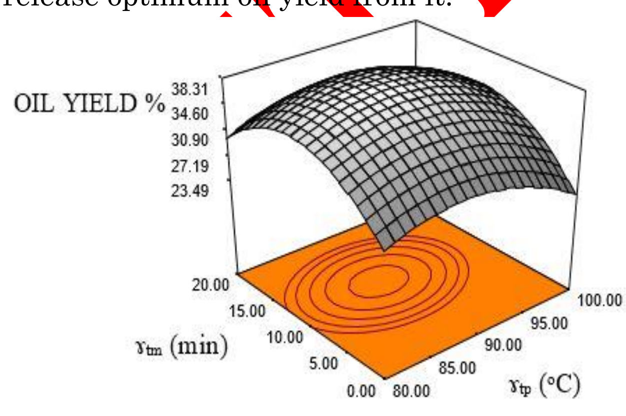

Figure 7. Roasting time and roasting temperature against oil yield.

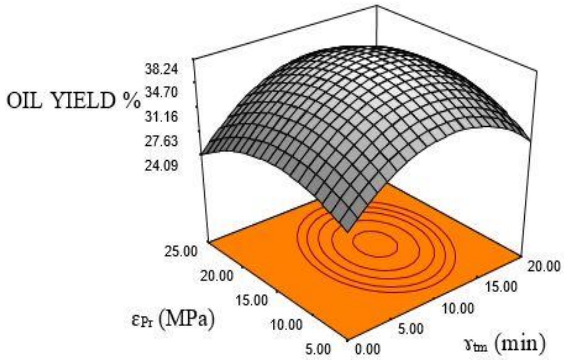

Figure 8. Expression pressure and roasting time against oil yield.

Findings from Ajibola *et al.* (1993); Alonge *et al.* (2003); Bamgboye and Adejumo (2011) are all in agreement with this heat treatment observed for sandbox seed, which was attributed to the phenomenon of oilseeds undergoing concurrent decrease in moisture content, oil viscosity and protein coalescence by heat injection, which enhances oil expression. However, at higher temperatures, excessive moisture loss can occur, causing seed hardening, thereby reducing the oil yield. This observation conforms to findings on dika nut, groundnut, and shea kernel respectively (Olaniyan and Oje, 2007; Abidakun *et al.*, 2012; Olajide *et al.*, 2014;).

Roasting the sandbox samples up to 15 min increased the oil yield (Figures 7-8). It was observed that the oil yield was least for the un-roasted sample which represents the 0-minute roasting time. The unroasted samples yielding the lowest oil is an indication of the importance of heat-treating oil samples before extraction. Sandbox oil yield decreased at roasting time above 15 min. Kagwacie and Anozie (1995) observed that the flow of oil is inversely proportional to the kinematic viscosity. Thus, as heat treatment progresses, kinematic viscosity of samples is lowered for oil to flow. According to Fakayode and Ajav (2016), heating oilseed samples at lowered temperatures requires more time to allow for the adjustment of moisture content to the optimum level that would lead to the folding of oil vessels, congealing of protein and allow flowability, but heating at higher temperature would take shorter time to reach these conditions, that additional heat would cause a reduction in oil yield. Movement of moisture during heat treatment creates a vacuum which becomes an accommodating capacity for the rupturing oil capillaries as heating continue. Oil yield is higher and faster and proportional to the rate of protein coalescence and decline in kinematic viscosity (Ajibola *et al.*, 2000; Akintunde *et al.*, 2001). This phenomenon enables the emergence of oil from the oil tubes into the inter-grain vacuum (Adeeko and Ajibola, 1990). This occurrence could be obtained at higher roasting temperatures and short time respectively, while extended roasting time at higher temperatures causes drastic drop in moisture content, leading to hardening of oilseeds which results in decrease in oil yield. The sandbox oil yield was highest when seed samples were roasted at 85°C for 15 min (Figures 7-8). Similar conditions were reported for groundnut and sheanut (Adeeko and Ajibola, 1990; Olajide, 2000; Ajav and Olatunde, 2011).

The sandbox oil yield was observed to increase with increase in expression pressure of 5-20 MPa, which decreased as the pressure increased to 25 MPa (Figures 8-9). It was observed that the pressed sandbox mash slurried and clogged the screw press oil holes and overflowing the pressing plate at pressure above 20 MPa. This may be that at pressing pressure beyond 20 MPa, the sandbox oil bearing capillaries were crushed, hence blocking the flow of oil. Bamgboye and Adejumo (2011) observed that seed cells rupture during oil expression due to pressure on seed cell walls, which causes them to release their lipid contents. Conversely, as the applied pressure increases, oil capillaries are repeatedly compressed, disrupted and could eventually become blocked (Ward, 1976). This finding on sandbox seed is similar to reports on other oilseeds and nuts: groundnut, rice bran, melon, roselle, dika, soybean, conophor (Fasina and Ajibola, 1989; Adeeko and Ajibola, 1990; Ajibola *et al.*, 1990; Sivala *et al.*, 1992; Akintunde *et al.*, 2001; Bamgboye and Adejumo, 2011; Ogunsina *et al.*, 2014).

The sandbox oil yield increased with increase in expression time from 2-8 min and dropped as the pressing time exceeded 8 min (Figure 9). The result is similar to those reported by Olajide *et al.* (2014) on groundnut kernel and Mwithiga and Moriasi (2007) on soybeans.

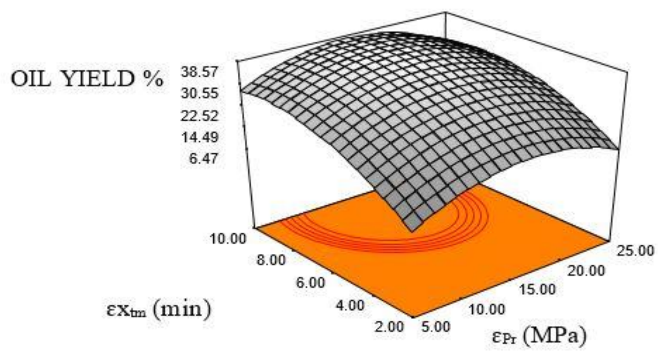

Figure 9. Roasting temperature and moisture content against oil yield.

Response surface optimization of oil extraction from sandbox seed

Out of the four models of the RSM software, the one chosen for the prediction of oil yield from sandbox seed by mechanical means was based on the model with the best statistics as regards the polynomial order with the largest number non- aliasing significant additional terms, insignificant lack-of-fit and high Adjusted and Predicted *(R^2)*. The quadratic model with the highest R^2 and lower standard deviation values (Table 2) was selected.

Table 2. Model comparison.

Statistics	Models			
	Linear	**2Factorial Interaction**	**Quadratic**	**Cubic**
Standard Deviation, SD	4.84	5.86	3.72	2.21
R^2	0.5623	0.6053	0.8907	0.9789
Mean	29.39	29.39	29.39	29.39
Adjusted R^2	0.4781	0.2353	0.6921	0.8909
Coefficient of Variation, C.V.	16.47	19.93	12.65	7.53
Predicted R^2	0.3910	-2.1284	-1.8079	-19.9477
PRESS	847.71	4352.06	3906.19	29140.84
Adequate Precision	9.272	5.449	7.280	10.349

PRESS = Predicted Sum of Square.

Mathematical relationship for predicting oil yield from sandbox relatively to the process factors is given in Equation 5.

$$OY = 35.35 - 1.5mc - 0.03\gamma_{tp} + 2.5\gamma_{tm} + 0.49\varepsilon_{Pr} + 4.8\varepsilon x_{tm} - 1.91mc^2 + 0.086\gamma_{tp}^2 - 2.41\varepsilon_{Pr}^2 - 1.83\varepsilon x_{tm}^2 + 0.39mc\gamma_{tp} - 0.098mc\gamma_{tm} - 1.09mc\varepsilon_{Pr} - 0.64mc\varepsilon x_{tm} - 0.27\gamma_{tp}\gamma_{tm} + 0.058\gamma_{tp}\varepsilon_{P} + 0.47\gamma_{tp}\varepsilon x_{tm} + 1.04\gamma_{tm}\varepsilon_{Pr} + 0.74\gamma_{tm}\varepsilon x_{tm} - 0.30\varepsilon_{Pr}\varepsilon x_{tm} \quad (5)$$

[SD = 3.72, R^2 = 0.8908, Mean = 29.39, Adjusted R^2 = 0.6922, C.V. = 12.66, Predicted R^2 = –1.8061, PRESS = 3910.93, Adequate Precision = 7.301 and F-value of 4.49 (Tables 2 and 3)]

OY = Oil Yield (%), *mc* = moisture content of sandbox seed, γ_{tp} = Roasting temperature, γ_{tm} = Roasting time, ε_{Pr} = Expression pressure and εx_{tm} = Extraction time

From the equation, the oil yield varies directly with factors with positive sign and inversely with factors with negative sign. The values of "Prob > F" in Figure 3, lower than 0.05, such as γ_{tm}, εx_{tm}, mc^2, γ_{tm}^2, ε_{Pr}^2, and εx_{tm}^2, represents significant model parameters for sand box oil extraction.

Table 3. ANOVA for Response Surface Quadratic Model of the Oil Extraction

Source	Sum of squares	DF	Mean square	F value	Prob > F
Model	1241.52	20	62.08	4.49	0.0069^s
mc	58.56	1	58.56	4.23	0.0642
γ_{tp}	0.022	1	0.022	0.0016	0.9688
γ_{tm}	151.76	1	151.76	10.97	0.0069^s
ε_{pr}	5.82	1	5.82	0.42	0.5299
ε_{tm}	568.13	1	568.13	41.06	0.0001^s
mc^2	106.76	1	106.76	7.47	0.0180^s
γ_{tp}^2	0.22	1	0.22	0.016	0.9026
γ_{tm}^2	103.43	1	103.43	7.47	0.0194^s
ε_{pr}^2	171.01	1	171.01	12.36	0.0048^s
ε_{tm}^2	98.39	1	98.39	7.11	0.0219^s
$mc\gamma_{tp}$	2.44	1	2.44	0.18	0.6825
$mc\gamma_{tm}$	0.15	1	0.15	0.011	0.9179
$mc\varepsilon_{pr}$	18.86	1	18.86	1.36	0.2677
$mc\varepsilon_{tm}$	6.46	1	6.46	0.47	0.5084
$\gamma_{tp}\gamma_{tm}$	1.14	1	1.14	0.082	0.7795
$\gamma_{tp}\varepsilon_{pr}$	0.054	1	0.054	0.004	0.9513
$\gamma_{tp}\varepsilon_{tm}$	3.51	1	3.51	0.25	0.6246
$\gamma_{tm}\varepsilon_{pr}$	17.28	1	17.28	1.25	0.2875
$\gamma_{tm}\varepsilon_{tm}$	8.69	1	8.69	0.63	0.4449
$\varepsilon_{tp}\varepsilon_{tm}$	1.47	1	1.47	0.11	0.7506
Residue	152.21	11	13.84		
Lack of fit	149.68	6	24.95	49.25	0.0003^s
Pure Error	2.53	5	0.51		
Cor Total	1393.74	31			

The quadratic model had a high R^2 of 0.8908 and very low p-value of less than 0.0001 and thus was concluded to be significant (Table 4). The R^2 of 0.89 is an indication of a direct relationship between the oil yield and the process factors, showing 89.08% confidence that the model explained 89.08% of every irregularity as regards the process factors and oil yield.

Table 4. Test of between-subjects effect of process conditions on oil yield from sandbox seed

Source	df	Mean Square	F	Significance
Corrected Model	27	51.439	86.003	0.0001^{s}
Intercept	1	10656.051	17816.504	0.0001^{s}
mc	3	67.567	112.970	0.0001^{s}
Υ_{tp}	2	4.189	7.004	0.049
Υ_{tm}	2	122.883	205.456	0.0001^{s}
ε_{Pr}	2	124.977	208.957	0.0001^{s}
εx_{tm}	2	164.746	275.449	0.0001^{s}
Error	4	0.598		
Total	32			
Corrected Total	31			

The 4.49 model F-value (Table 3) indicated that the model effectively explained the inter-relationships between process factors and oil yield. The quadratic curve relationship is one of optimum and minimum. That means that there are process parameters values in which oil yield would be optimum or minimum. The sandbox seed grain is very soft, similar to melon seed, thus a mild roasting temperature of 85°C for 15 min was enough heat treatment to release optimum oil yield from it. The sandbox mash slurried and clogged the screw press oil holes and overflowing the pressing plate at pressure above 20 MPa and pressing time above 8 min and moisture content above 6% wb. The optimum oil yield for sandbox seed was obtained at the process variable ranges. From the findings, process parameter values for optimal sandbox oil yield were determined. Findings from Ebewele *et al.* (2010); Bamgboye and Adejumo (2011); Olajide *et al.* (2014); Yusuf *et al.* (2014); Aremu and Ogunlade (2016); Akubude *et al.* (2017) agrees with this finding as regards mechanical oil expression.

Model validation

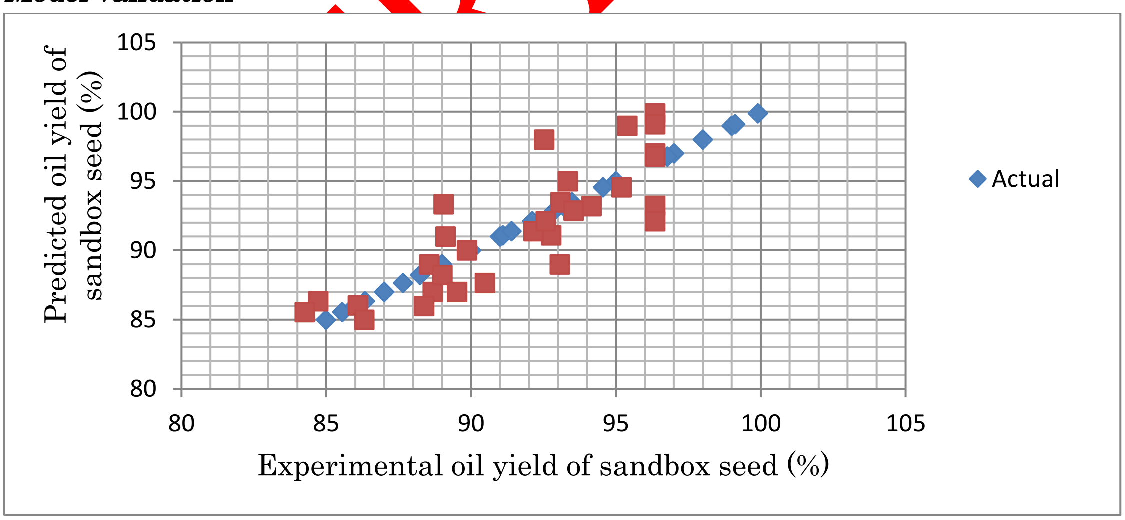

Figure 10. Predicted oil yield against actual oil yield

A similarity plot of correlation relationship of the laboratory results and predicted results of oil yield from the sandbox seed is shown in Figure 10. The R^2 of 0.8908 of the relationships is an indication of high correlation between the predicted oil yield values and the values gotten from the actual experiment. This is an indication that without distortions that accompany practical experiments, the model represents a reliable equivalent for the estimation of extractable oil from sandbox seed by mechanical means within the range of process variables studied. At the range of process factors: 8-12% wb moisture content, 80-100°C roasting temperature, 0-20 min roasting time, 5-25 MPa expression pressure and 2-10 min expression time, the maximum oil yield of 38.68% was obtained at 6% wb moisture content, 85°C roasting temperature, 15 min roasting time, expression pressure of 20 MPa and 8 min pressing time, while the predicted optimum oil yield was 38.95% at processing conditions of 7.03% moisture content, 97.72°C roasting temperature, 11.32 min roasting time, 15.11 MPa expression pressure and 8.57 min extraction time. Experiments carried out under the predicted optimum conditions produced an oil yield of 38.90%, validating the predicted oil yield and the processing conditions. The variations between the experimental and predicted results were low at the ranged 0.01-0.62. This is an indication that model used reasonably predicted the oil yield from sandbox seed by mechanical screw press.

CONCLUSION

Oil extraction process from sandbox seed using screw press was optimized. From the variations of process factors studied, the extracted oil from sandbox seed varied from 16.38-38.68%. The 38.68% oil yield, which was the highest, was attained at the process factor combination of 6% wb moisture content, 85°C roasting temperature, 15 min roasting time, 20 MPa expression pressure and 8 min pressing time. The model maximum predicted oil yield was 38.95% at 7.03% moisture content, 97.72°C roasting temperature, 11.32 min roasting time, 15.11 MPa expression pressure and 8.57 min extraction. Experiments carried out under the predicted optimum conditions produced an oil yield of 38.90%, validating the predicted oil yield and the processing conditions. The variations between the experimental and predicted results were low at the range of 0.01-0.62. All process factors considered seem to have greatly influenced the oil yield, with roasting temperature been insignificant. The model developed for the sandbox oil expression, with R^2 of 0.8908 indicates a high correlation between the process factors. The similarity between the values oil yield from actual experiment and predicted values, indicates that the model adequately predicted the oil yield from sandbox seed by mechanical expression.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

David Nwabueze ONWE: Conceptualization, Sample collection, Methodology, Investigation, Data collection, Analysis, Validation, Writing of Report.
Adeleke Isaac BAMGBOYE: Supervision, Visualization, Review, Correction and Editing of Report.

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