



Three leaved yam starch physical / engineering properties evaluation using Response Surface Methodology and Artificial Neural Network network

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ARTICLE INFO

Keywords:

ANN
Engineering properties
RSM
TLYS starch

ABSTRACT

This study evaluated some physical properties of three-leaved yam starch (TLYS). The angle of repose (AOR) (wood and glass), bulk density, true density, bulk volume, and surface area were analyzed with varying temperatures (60 °C, 67.5 °C, and 75 °C) at a constant air velocity (1.75 m/s), as temperature increased, the AOR glass decreased significantly. In contrast, the AOR metal increased, the highest bulk density (0.61 kg/m³) was observed at 75 °C, bulk volume and bulk density decreased significantly with an increase in temperature, and surface area increased with an increase in temperature. The effect of the operating parameters (time, temperature, and air velocity) on the responses (bulk density, true density, bulk volume, and surface area) was investigated, modeled, and optimized via Response Surface Methodology (RSM). The Analysis of Variance (ANOVA) showed a second-order polynomial model with bulk density (R^2 - 0.999, Adj R^2 -0.9997, Pred R^2 - 0.9979), true density (R^2 - 0.999, Adj R^2 -0.9997, Pred R^2 -0.9977), bulk volume (R^2 - 0.9970, Adj R^2 -0.9932, Pred R^2 -0.9527) and surface area (R^2 - 0.9953, Adj R^2 -0.9892, Pred R^2 -0.9247) indicating a close relationship between the experimental and predicted responses. The 3D graphs showed a significant impact of the process factors on the response. The optimal bulk density (0.81 kg/m³), true density (0.55 kg/m³), bulk volume (25 m³), and surface area (684 m²) were obtained at a temperature (57.5 °C), time (3 h), and air velocity (2.25 m/s). Artificial Neural Network (ANN) technique with 3 backpropagation algorithm (B-P.) algorithm was employed to analyze TLYS engineering properties; each algorithm was evaluated with 3 neurons in the input layer, 10 neurons in the hidden layer, and an output layer with four neurons. Coefficient of determination (R^2) and mean square error (M.S.E.) have been implemented and correlated to test the adequacy of the model. Results showed that the Bayesian regularization had the best prediction for all the algorithms with an MSE (2.5465E-9) and R^2 (9.999E-1) for the responses. Scanning Electron Micrograph (SEM) and proximate analysis indicate that the TLYS contains starch. This information from this study can be effectively utilized in the design parameters of the TLYS post-harvest process/machinery. Hence the post-harvest process evaluates the nutritional quality, protects food safety, and reduces losses between harvest and consumption.

1. Introduction

The family *Dioscoreaceae* comprises the three-leaved yam (*Dioscorea dumetorum*) [1]. Other popular names for it include cluster yam, African bitter yam, wild yellow yam, and trifoliate (three-leaved) yam. In Ojoto and several Igbo-speaking regions of southeast Nigeria, the three-leaved

yam is referred to as “jiuna” or “jiona” and is regarded as a meal for adults [2]. Even though it is a great source of phyto-proteins, the three-leaved yam is one of the many tropical tubers that still need to be fully utilized and are in threat of extinction [3].

It could be utilized as a source of low-cost, high-yield raw ingredients for food production. The dried tubers can be used as a base for beer

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<https://doi.org/10.1016/j.jafr.2023.100746>

Received 28 February 2023; Received in revised form 10 August 2023; Accepted 19 August 2023

Available online 25 August 2023

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brewing in breweries. Like certain other yams, the tubers can be properly processed to make yam flakes, quick flour for the bread industry, or starch for various pharmacological treatments [4]. The three-leaved yam is a favorite meal of diabetics and is also used as medicine for several illnesses. Trifoliate yam is used to cure malaria in Southern Nigeria [5], indicating the plant's widespread use in traditional medicine.

The engineering properties of the agricultural product are important for the design and construction of equipment or analysis of the behavior of products to perform various post-harvest operations [6]; bulk and true densities of the materials are important to design machines for its conveying, sorting, sizing, harvesting, processing, transportation, and storing the product [7]. Its angle of repose is important for package designing or storage structures [8]. It also applies the knowledge of heat and moisture transport in energy savings and product quality [9,10]. Determination of root crop physical properties is highly relevant for efficient mass transfer analysis and reproducibility of quality-controlled products [1,3].

Response surface methodology (RSM) is a typical statistical technique for modeling and optimizing. It employs a sequence of designed experiments to get the best possible outcome, and the model generated is always simple to estimate and use [11]. Its advantage over one factor at a time (OFAT) technique, such as the evaluation of interaction effect, higher precision estimates, and its requirements for fewer resources, makes it a suitable tool for analyzing experiments [12]. [3] have reported on the energy and exergy analysis of three-leaved yam drying modeling and optimization. Hence the optimized energy efficiency (99.22%) and exergy efficiency (75.09%) based on the process parameters (time-3 hours, temperature- 60 °C, and air velocity-1.5 m/s) can be applied in the design and development of a three-leaved yam drier.

An artificial neural network (ANN) is a computer tool for information processing that draws inspiration from the biological nervous system [13]. It features input, hidden, and output layers, and by repeatedly training the input-output system, it is particularly capable of handling the modeling and simulation of a very intricate and nonlinear correlation between the independent variables and the dependent variable [14, 15]. Using ANN, Oke et al. (2021) successfully predicted three-leaved yam energy and exergy parametric analysis.

Various researchers have reported on the physical properties of agricultural products such as cocoyam [16], African yam beans [17], Cassava grit [18], Bambara nut [19], Acha flour and pigeon pea [20] establishing their post-harvest operations from the developed data. However, there needs to be more information on the physical properties prediction of three-leaved yam. This study finds novelty by evaluating the process parameter effects, modeling, optimizing three-leaved yam physical/engineering properties for post-harvest operations, and comparing it with ANN. Understanding these properties is essential for designing equipment for milling, handling, storing, transporting, controlling, and optimizing food processing operations.

2. Materials and method

2.1. Materials and equipment

Fresh three-leaved yam tubers were procured from Ndioru market, Ikwuano L.G.A, Abia state. Electronic compact scale balance (AUW320, Shimadzu, China), Hygrometer (AT-303C, Shangdong, China), Anemometer (AM4206, Delhi, India), Multi Thermometer (ST9283, Mextech, India), Digital Vernier calliper, Angle of repose device, grating machine, Muslin cloth, Shaped rectangular plastic plate, Round pan, Electro thermal oven (Heratherm Oven CP 210997, U.S.A.)

2.2. Starch extraction and characterization

Three leaved yam tubers were hand peeled and washed in clean water. A locally made grater was used to crush the peeled tubers. A

sufficient amount of water was added to the resulting pulp. The slurry was mixed with distilled water on a ratio of 5:1 by volume, and the fiber was then filtered through a screen measuring 75 mm. After 10 h of settling, the starch milk was decanted from the supernatant. The starch was continuously washed with fresh water after being re-dissolved in water. Next, using a rectangular mold, 30 g of the starch was formed into a rectangle with a thickness of 45 mm by 25 mm by 4.25 mm. Using the AOAC (2003) technique, proximate analysis was conducted on the dried sample to test for crude fiber, crude fat, and pH. A starch granule micrograph was obtained using a JSM 35 Genie Scanning Electron Microscope (SEM); the angle of repose, bulk density, true density, bulk volume, and surface area were evaluated.

2.2.1. Determination of amylose in three-leaved yam starch

According to (AOAC 2003), 100 mg of the starch was added to 1 ml of distilled ethanol and 10 ml of NaOH and left overnight; the solution was made up to 100 ml. Next, 2.5 ml of the solution was added to 20 ml distilled water, and three drops of phenolphthalein, 0.1 N HCl, were added drop by drop until the pink color disappeared. Then 1 ml of iodine reagent was added, and the volume was up to 50 ml. After 30 min at room temperature, absorbance was read at 620 nm for the dispersed starch with distilled water as the reference. Finally, a standard 1 ml amylose solution was used to develop the color for the sample. The amount of amylose present was calculated using the formula below.

Absorbance = 2.5 ml of test solution = 'x' mg of amylose

$$100\text{ml contains} = ('x' + 2.5) \times 100\text{mg amylose} = \% \text{ amylose} \quad (1)$$

2.3. Determination of engineering properties of the three-leaved yam starch

2.3.1. Determination of moisture content

The moisture content of the samples was measured using a drying process using the equation.

$$M_d = \frac{W_w - W_d \times 100}{W_d} \quad (2)$$

Where: M_d is the moisture content dry basis (%).

W_w is the initial weight of the starch sample;

W_d is the dry weight of the starch sample.

2.3.2. Determination of bulk volume

[21]'s description of Archimedes's principle was used to calculate the bulk volume of the starch. The starch sample was fastened with nylon to prevent it from contacting water. It was then weighed and placed in a measuring cylinder with a known volume of water, causing the water volume to rise (increase). The bulk volume of the seed is the difference between the current water level and the initial water level in the measuring cylinder.

2.3.3. Determination of bulk density

The bulk density of the sample was determined as the ratio of the bulk weight of the dried starch to the bulk volume.

$$pb = \frac{W_s}{V_s} \quad (3)$$

Where pb = Bulk density (kg/m^3), W_s = weight of the sample (kg), V_s = Volume occupied by the sample (m^3).

2.3.4. Determination of true density

The true density was determined by weighing a sample and dividing it by the volume of water the sample displaced.

$$\text{Individual mass} - \quad (4)$$

Table 1

Summary of the experimental factors coding.

Factor	Name	Units	Type	Level		
				−1	0	1
A	Temperature	°C	Numeric	40	57.5	75
B	Time	Hour	Numeric	2	3	4
C	Air velocity	m/s	Numeric	1.5	2.25	3

Table 2

Proximate analysis for TLYS.

Parameter	Value
Crude ash, %	0.2 ± 0.02
Crude protein, %	5.577 ± 0.005
Crude fibre, %	Nil
Crude fat%	0.012 ± 0.0011

Table 3

Physicochemical characterization for TLYS.

Parameter	Value
Amylose, %	21.50 ± 0.003
pH	5.85 ± 0.004

Individual volume

2.3.5. Determination of angle of repose

Starch was applied to each of the three materials (wood, glass and metal) separately and allowed to slide down and assume a natural slope to determine the best material on which it slides. The angle of repose was then measured using an angle of repose device with three different materials: wood, glass, and metal. This is done to determine the value of designing the hoppers and other conveying equipment for agricultural machinery. The relationship given by Ref. [22] was applied to the measurements of the height (h) of the free surface of the starch and the length (l) of the heap formed outside the box to determine the angle of repose: the length (l) of the heap that formed outside the box and the height (h) of the seeds' free surface:

$$\theta = \tan^{-1} \left(\frac{h}{l} \right) \quad (5)$$

2.3.6. Determination of surface area

The surface area S in mm^2 was estimated by the relationship given by Ref. [23]:

$$S = \pi G m^2 \quad (6)$$

Where: Gm is the geometric mean diameter (mm) and.

S is the surface area of the dried three-leaved yam starch (mm^2).

All the analyses for moisture content, bulk volume, bulk density, true density, angle of repose, and surface area were done in triplicates, and the average value was used for further analysis.

2.4. Experimental design

Using Box-Behnken experimental design on three variables and a three-level basis, the experiment was developed using Design-Expert version 10. Temperature, time, and air velocity are the three independent variables considered in this study. The response variables employed were bulk density, true density, bulk volume, and surface area. Table 1 gives an overview of the experimental research design. The justification for the range of the independent variables was based on the report by Ref. [24] on optimizing the nutrient quality of pumpkin by convective drying.

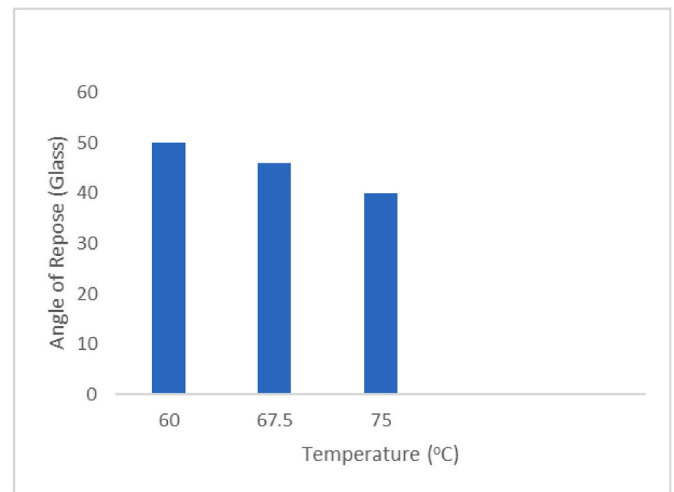


Fig. 1. Effect of temperature ranging from 60 °C to 75 °C on the angle of repose using glass at a 1.75 m/s air velocity.

3. Results and discussion

3.1. The proximate composition

Tables 2 and 3 display the findings of the TLYS proximate composition and physicochemical characterization, respectively. It demonstrates that the availability of starch is indicated by its ash level of 0.2%, crude protein content of 5.577%, insignificant quantity of fiber, pH of 5.85, and amylose content of 21.50%. The table demonstrates that TLYS has sufficient starch for post-harvest processing.

3.2. Angle of repose (AOR) using glass

3.2.1. Effect of temperature on the angle of repose using glass at a 1.75 m/s air velocity

The effect of temperature at 1.75 m/s air velocity on the angle of repose using glass for the dried three-leaved yam starch was studied for temperature values ranging from 60 to 75 °C and is shown in Fig. 1 below.

Experimental results in Fig. 1 showed that the angle of repose using glass at 1.75 m/s air velocity for the dried three-leaved yam starch depended on the temperature. As the drying system's temperature increases, the repose angle decreases. The highest value was observed at 60 °C, which decreased as the temperature increased to 75 °C. The surface layer of moisture surrounding the particle holds the grain aggregate together by surface tension, which causes the angle of repose

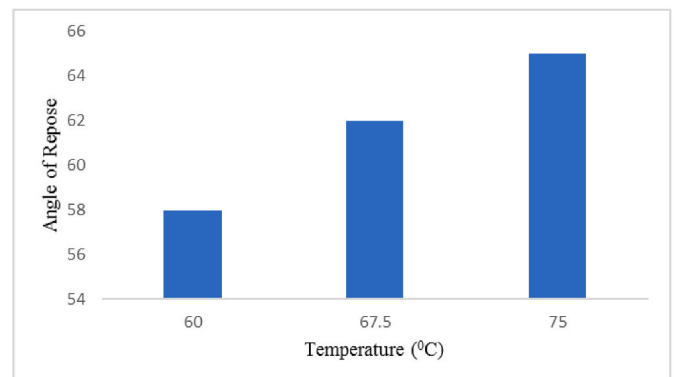


Fig. 2. Effect of temperature ranging from 60 °C to 75 °C on the angle of repose using metal at 1.75 m/s air velocity.

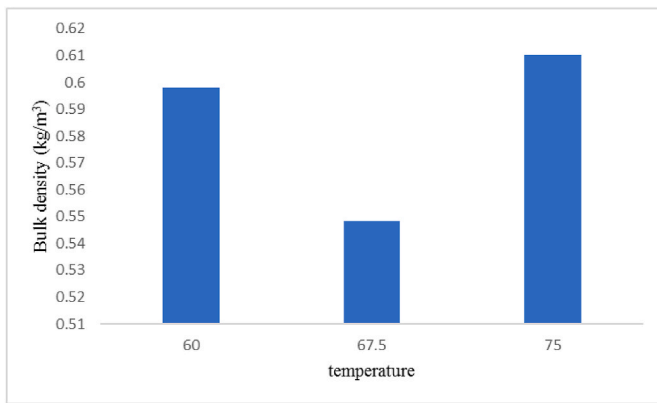


Fig. 3. Effect of temperature ranging from 60 °C to 75 °C on bulk density at a 1.75 m/s air velocity.

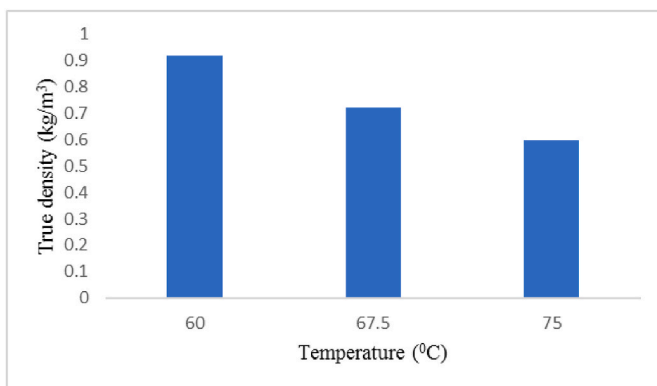


Fig. 4. Effect of temperature ranging from 60 °C to 75 °C on true density at a 1.75 m/s air velocity.

to increase with moisture content [25]. This suggests that friction increases on the surface of the rhizomes as water content increases, which reduces the capability of the seeds to flow over one another. Also, a similar trend was reported by Ref. [26] on the Physical Properties of Ginger (*Zingiber Officinale*).

3.3. Angle of repose (AOR) using metal

3.3.1. Effect of temperature on the angle of repose using metal at a 1.75 m/s air velocity

The effect of temperature on the angle of repose using wood at 1.75 m/s air velocity for the dried three-leaved yam starch was studied for temperature values ranging from 60 °C to 75 °C and is shown in Fig. 2 below.

Experimental results in Fig. 2 showed that the angle of repose using metal for the dried three-leaved yam starch at 1.75 m/s air velocity depended on the temperature. The angle of repose using metal increased from 60 to 75 °C as the temperature increased. The observed increase in the angle of repose can be attributed to the fact that the attractive forces between the dried sample and the metal surface decrease as the moisture content of the dried sample reduce [27].

3.4. Bulk density

3.4.1. Effect of temperature on bulk density at a 1.75 m/s air velocity

The effect of temperature on the bulk density at 1.75 m/s air velocity for the dried three-leaf yam starch was studied for temperature values ranging from 60 °C to 75 °C.

It was observed that there was inconsistency in the values of the bulk

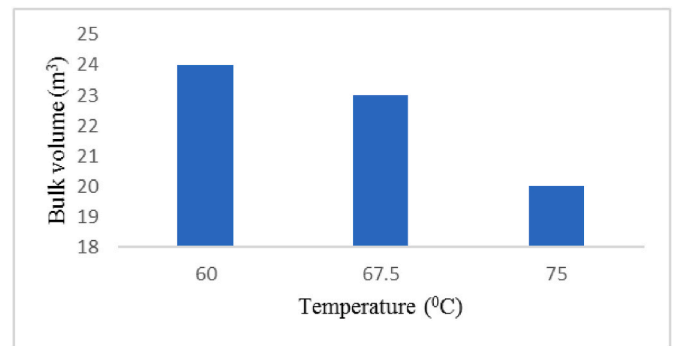


Fig. 5. Effect of temperature ranging from 60 °C to 75 °C on bulk volume at 1.75 m/s air velocity.

density at 1.75 m/s air velocity as the drying temperature increased in Fig. 3. The bulk density increased as the temperature increased, which caused a reduction in moisture content. The highest value was observed at a temperature of 75 °C.

[28] showed a similar tendency for chickpea seeds, Irtwange and Igbeke (2002) for African yam bean [29], for lablab seeds [30], for areca nut kernels, and [31] for round red lentil grains. Bulk density has been reported to have practical uses in heat transfer issue calculations, estimating the Reynolds number in pneumatic and hydraulic material handling, and predicting physical structure and chemical composition (Irtwange and Igbeke, 2002).

3.5. True density

3.5.1. Effect of temperature on true density at a 1.75 m/s air velocity

The effect of temperature on true density at 1.75 m/s air velocity for the dried three-leaved yam starch was studied for temperature values ranging from 60 °C to 75 °C and is shown in Fig. 4 below.

Experimental results in Fig. 4 showed a decrease in the true density of the dried three-leaved yam starch at 1.75 m/s air velocity as the temperature of the drying system increased. This can be attributed to the fact that the decrease in the moisture content of the starch as the temperature increases leads to the displacement of a smaller volume of water and also a reduction in the mass of the starch, which are all independent factors in which the true density depends on [32,33].

3.6. Bulk volume

3.6.1. Effect of temperature on bulk volume at 1.75 m/s air velocity

The effect of temperature on the bulk volume of the dried three-leaved yam starch at 1.75 m/s air velocity was studied for temperature values ranging from 60 °C to 75 °C and is shown in Fig. 5 below.

Experimental results in Fig. 5 showed that the bulk volume for the dried three-leaved yam starch at 1.75 m/s air velocity was dependent on the temperature. The effect of temperature on the bulk volume showed a decrease in the value of the bulk volume as the temperature increased. The highest bulk volume was obtained at the highest temperature of 60 °C, while the lowest was at a temperature of 75 °C.

The volumetric increase can be attributed to the axial dimensions expanding, which contributed to the weight increase of the rhizomes, resulting in the displacement of excess liquid; this observation is consistent with the study carried out by Ref. [26] on the Physical Properties of Ginger (*Zingiber Officinale*).

3.7. Surface area

3.7.1. Effect of temperature on the surface area at 1.75 m/s air velocity

The effect of temperature on the surface area of the dried three-leaved yam starch at 1.75 m/s air velocity was studied for

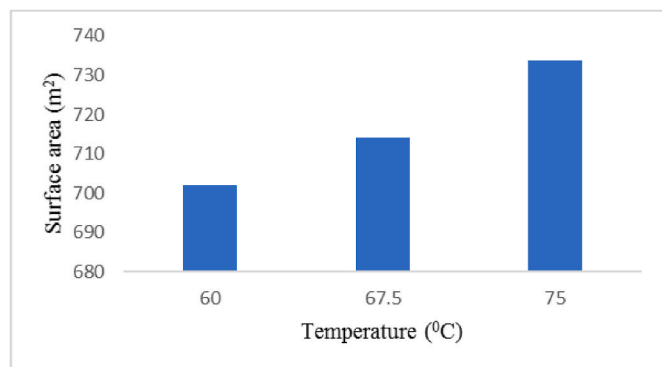


Fig. 6. Effect of temperature ranging from 60 °C to 75 °C on the surface area at 1.75 m/s air velocity.

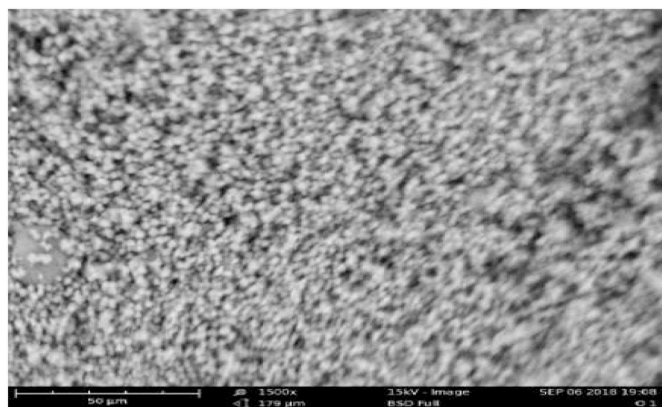


Fig. 7. SEM analysis of three-leaved yam starch.

temperature values ranging from 60 °C to 75 °C and is shown in Fig. 6 below.

Fig. 6 above showed that the dry three-leaved yam starch's surface area at 1.75 m/s air velocity depended on the temperature. The surface area increases as the temperature increases. However, the highest increase was observed at the temperature of 75 °C. This can be attributed to a low moisture percentage in the dried sample as the drying temperature increases and reduces the sample's surface area [34].

3.8. SEM analysis

The SEM result of three-leaf yam starch is shown in Fig. 7. The biochemistry of the chloroplasts or amyloplasts, as well as plant physiology, influence the shape of the starch granules [35]. Moreover, various variables, including environmental factors such as temperature, storage, and cultural traditions, can influence starch granules' physicochemical and thermal characteristics [36].

The size and form of bitter yam starch granules might vary depending on the tuber's source and cultivar [37]. Eliminating cracks on the surface of starch granules, as detected under scanning electron microscopy, is another common method for determining starch purity following extraction [38].

Previous research has found that bitter yam starch contains significantly smaller granules (3–5 µm) than granules from other yam species (>21 µm) [39], which may explain their lower amylose concentrations [40]. It has been proposed that the amylose component of starch is largely generated when yam granules get bigger, with larger granules containing more amylose than smaller ones [40,41]. In terms of morphology, bitter yam starch was discovered to be polygonal [39,42], in contrast to other yam kinds that were oval, round, or triangular [42]. Differences in starch granule size and shape might be linked to varietal changes, source, and even growth circumstances. Because of their bitter taste, small-sized starch granules have been proposed as potential lipid replacements in food systems. Bitter yam starch may therefore find use as a fat substitute in some food industry applications, such as stabilizers in baking powder and as laundry-stiffening agents, since it may permeate fabric and provide high gloss and stiffness in textile industries [42].

The experimental design matrix for bulk density, true density, bulk volume, and surface area of TLYS was analyzed with Box Behnken design in Design Expert 10.0 in Table 4. The experimentally determined values of the response are presented in Table 4. The data and responses elaborated on the impact of varying the process parameters on the engineering properties of TLYS [3,43]. The experimental data's multiple regression analysis yielded a second-order polynomial equation, as indicated in equations (7)–(10). The one-factor coefficient indicates the influence of a single variable. However, the two-factor and second-order coefficients show the interaction of two factors and the quadratic impact. A positive sign before the conditions has a synergistic impact, whereas a negative sign has an antagonistic effect.

$$\begin{aligned} \text{bulk density} = & 0.81 - 0.0025A - 0.00375B + 0.00875C + 0.038AB \\ & + 0.063AC + 0.1BC - 0.098A^2 - 0.095B^2 - 0.09C^2 \end{aligned} \quad (7)$$

Table 4
Experimental run for some TLYS engineering properties.

Run	temperature °C	time hours	air velocity m/s	bulk density kg/m ³	true density kg/m ³	bulk volume m ³	surface area m ²
1	57.5	2	1.5	0.52	0.43	21.85	728.25
2	75	4	2.25	0.65	0.45	26.44	717
3	57.5	3	2.25	0.81	0.55	25	684
4	57.5	2	3	0.74	0.51	23.39	685.75
5	40	3	3	0.57	0.49	20.93	707.25
6	57.5	4	3	0.53	0.54	23.64	727.75
7	40	4	2.25	0.58	0.79	22.35	734
8	57.5	3	2.25	0.81	0.55	25	684
9	57.5	3	2.25	0.81	0.55	25	684
10	57.5	4	1.5	0.71	0.71	24.27	703.25
11	57.5	3	2.25	0.81	0.55	25	684
12	75	3	3	0.69	0.56	25.48	665.25
13	75	2	2.25	0.58	0.53	26.01	690
14	57.5	3	2.25	0.81	0.55	25	684
15	40	3	1.5	0.68	0.71	19.54	709.25
16	40	2	2.25	0.66	0.41	20.5	732
17	75	3	1.5	0.55	0.42	25.8	680.75

Table 5

ANOVA for Response Surface Quadratic Model for bulk density.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.19	9	0.021	5827.98	<0.0001	significant
A-temperature	5.000E-005	1	5.000E-005	14.00	0.0072	
B-time	1.125E-004	1	1.125E-004	31.50	0.0008	
C-air velocity	6.125E-004	1	6.125E-004	171.50	<0.0001	
AB	5.625E-003	1	5.625E-003	1575.00	<0.0001	
AC	0.016	1	0.016	4375.00	<0.0001	
BC	0.040	1	0.040	11200.00	<0.0001	
A ²	0.040	1	0.040	11207.37	<0.0001	
B ²	0.038	1	0.038	10640.00	<0.0001	
C ²	0.034	1	0.034	9549.47	<0.0001	
Residual	2.500E-005	7	3.571E-006			
Lack of Fit	2.500E-005	3	8.333E-006			
Pure Error	0.000	4	0.000			
Cor Total	0.19	16				
Std. Dev.	1.890E-003		R-Squared	0.9999		
Mean	0.68		Adj R-Squared	0.9997		
C.V. %	0.28		Pred R-Squared	0.9979		
PRESS	4.000E-004		Adeq Precision	200.079		

Table 6

ANOVA for Response Surface Quadratic Model for true density.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.18	9	0.019	5454.65	<0.0001	significant
A-temperature	0.024	1	0.024	6776.00	<0.0001	
B-time	0.047	1	0.047	13023.50	<0.0001	
C-air velocity	3.612E-003	1	3.612E-003	1011.50	<0.0001	
AB	0.053	1	0.053	14812.00	<0.0001	
AC	0.032	1	0.032	9072.00	<0.0001	
BC	0.016	1	0.016	4375.00	<0.0001	
A ²	5.921E-005	1	5.921E-005	16.58	0.0047	
B ²	6.579E-006	1	6.579E-006	1.84	0.2168	
C ²	6.579E-006	1	6.579E-006	1.84	0.2168	
Residual	2.500E-005	7	3.571E-006			
Lack of Fit	2.500E-005	3	8.333E-006			
Pure Error	0.000	4	0.000			
Cor Total	0.18	16				
Std. Dev.	1.890E-003		R-Squared	0.9999		
Mean	0.55		Adj R-Squared	0.9997		
C.V. %	0.35		Pred R-Squared	0.9977		
PRESS	4.000E-004		Adeq Precision	263.897		

Table 7

ANOVA for Response Surface Quadratic Model for bulk volume.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	69.24	9	7.69	262.43	<0.0001	significant
A-temperature	52.07	1	52.07	1776.09	<0.0001	
B-time	3.06	1	3.06	104.47	<0.0001	
C-air velocity	0.49	1	0.49	16.72	0.0046	
AB	0.50	1	0.50	17.19	0.0043	
AC	0.73	1	0.73	24.93	0.0016	
BC	1.18	1	1.18	40.15	0.0004	
A ²	2.45	1	2.45	83.50	<0.0001	
B ²	0.72	1	0.72	24.44	0.0017	
C ²	7.12	1	7.12	242.71	<0.0001	
Residual	0.21	7	0.029			
Lack of Fit	0.21	3	0.068			
Pure Error	0.000	4	0.000			
Cor Total	69.45	16				
Std. Dev.	0.17		R-Squared	0.9970		
Mean	23.84		Adj R-Squared	0.9932		
C.V. %	0.72		Pred R-Squared	0.9527		
PRESS	3.28		Adeq Precision	52.761		

Table 8
ANOVA for Response Surface Quadratic Model for surface area.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	7312.42	9	812.49	164.56	<0.0001	significant
A-temperature	2096.28	1	2096.28	424.56	<0.0001	
B-time	264.50	1	264.50	53.57	0.0002	
C-air velocity	157.53	1	157.53	31.91	0.0008	
AB	156.25	1	156.25	31.65	0.0008	
AC	45.56	1	45.56	9.23	0.0189	
BC	1122.25	1	1122.25	227.29	<0.0001	
A ²	195.41	1	195.41	39.58	0.0004	
B ²	3169.75	1	3169.75	641.98	<0.0001	
C ²	0.15	1	0.15	0.030	0.8674	
Residual	34.56	7	4.94			
Lack of Fit	34.56	3	11.52			
Pure Error	0.000	4	0.000			
Cor Total	7346.99	16				
Std. Dev.	2.22		R-Squared	0.9953		
Mean	700.03		Adj R-Squared	0.9892		
C.V. %	0.32		Pred R-Squared	0.9247		
PRESS	553.00		Adeq Precision	40.084		

$$\text{true density} = 0.55 - 0.055A + 0.07625B - 0.02125C - 0.115AB + 0.09AC - 0.0625BC - 0.00375A^2 - 0.00125B^2 - 0.00125C^2 \quad (8)$$

$$\text{bulk volume} = 25 + 2.55125A + 0.61875B + 0.2475C - 0.355AB - 0.4275AC - 0.5425BC - 0.7625A^2 - 0.4125B^2 - 1.3C^2 \quad (9)$$

$$\text{surface area} = 684 - 16.1875A + 5.75B - 4.4375C + 6.25AB - 3.375AC + 16.75BC + 6.8125A^2 + 27.4375B^2 - 0.1875C^2 \quad (10)$$

ANOVA analyzed the statistical significance of each model term and their interactions in Tables 5–8. For bulk density, all the terms, except the single term (A), have a very significant effect on the bulk density. The C-V% of 0.28, the probability value of 0.0001, and the adequate precision of 200.079 indicate that the model is significant and robust for optimization. The lack of fit of the model was 0.000025, which is not significant; this also supports an excellent fit for the model. The coefficient of determination of R^2 expressed the fitness of the polynomial model adjusted R^2 and predicted R^2 , which were obtained as 0.999, 0.9997 and 0.9979, suggesting that the experimental data is consistent with the predicted data, also, for true density, all other terms are significant except for quadratic terms (B^2 and C^2) that are insignificant on the true density of TLYS, the CV% of 0.35, the probability value of 0.0001, adequate precision of 263.897, lack of fit 0.00025, R^2 of 0.9999, Adj R^2 of 0.9997 and predicted R^2 of 0.9977 indicates the significance and adequacy of the model, for the bulk volume, the overall terms are significant, adequate precision (52.761), CV% (0.72), R^2 , Adj R^2 and predicted R^2 of 0.9970, 0.9932 and 0.9527 indicates the acceptability of the regression model; for surface area, all terms are significant except the single term (C), R^2 , Adj R^2 and predicted R^2 of 0.9953, 0.9892 and 0.9247 indicates a good fit for the model, the adequate precision (40.084) and CV% (0.32) shows the model's acceptability, this is in agreement with reports from Ref. [24] on the improvement of the nutritional quality of pumpkin seeds using RSM based optimization. The coefficient of variation (CV) value of the model for the responses is less than 1% which is a relatively low value suggesting that an appropriate model has been established for the system. Also, adequate response precision is greater than 4, showing that it is a good model for navigating the design space. Lack of fit (LOF), which estimates the random errors in the obtained data, should be non-significant in relation to the model. The obtained lack of fit values confirms a non-significant LOF term. Hence the deviations in the obtained data are due to random errors. The correlation coefficients, which estimate the efficacy of the fit between

the obtained experimental data and the model, confirm that there is a reasonable fit statistically when the R^2 is close to 1. In the present work, all R^2 -values for the response are close to 1, confirming a good fitness between the experimental data and those suggested by the model.

3.9. Parametric analysis

The parametric analysis graph is shown in figures A1- A4 of Appendix A. An increase in temperature and time leads to a steady increase in bulk density up to 0.7kg/m³, then with a sudden decline for Fig. A 1; an increase in temperature and air velocity leads to an increase in bulk density up to 0.65kg/m³ with a decrease. An increase in time and air velocity increases bulk density to 0.7kg/m³. A combination of time and temperature leads to an increase in true density; a combination of air velocity and temperature leads to a decrease in true density; a combination of time and air velocity leads to an increase in true density in Fig. A2. A combination of time and temperature, air velocity and temperature, and time and air velocity led to an increase in bulk volume in Fig. A3, while the same combination of parameters led to a decrease in surface area in fig. A4 [3].

Figures B1 to B8 of Appendix B shows the diagnostic and influencing plots of the responses (bulk density, true density, bulk volume and surface area) of the TLYS process parameter properties; the normal probability plots indicates the residuals around the normal distribution, the residuals are close to the straight line, showing they are normally distributed [44]. A typical plot of the residuals versus the predicted response is shown in Figures B1 b, B3 b, B5 b and B7 b, with an expanding variance, it shows a need for transformation [45], a typical plot of the residuals versus the experimental run order is shown in Figures B1 c, B3 c, B5 c and B7 c, the plots have a random scatter and checks for lurking variables that may affect the response during the experiment. No trend was observed in the plot, this was confirmed by blocking and randomization [46]. The plot of the actual response versus the predicted was observed in figures B1d, B3 d, B5 d and B7 d, the points were distributed around a straight line indicating the level of predictability of the model.

The leverage versus runs is shown in Figures B2 a, B4 a, B6 a and B8 a for the responses (bulk density, true density, bulk volume and surface area) it measures the influence of each point on the fitted model. A leverage of 1 means that the model must go through that point, and leverages near one must be decreased by adding or replicating point. The Cook's distance versus runs (Fig. B2 b, B4 b, B6 b and B8 b) measures the change in the regression by deleting the case from the analysis. When a point is shown far from the other points, it must be investigated.

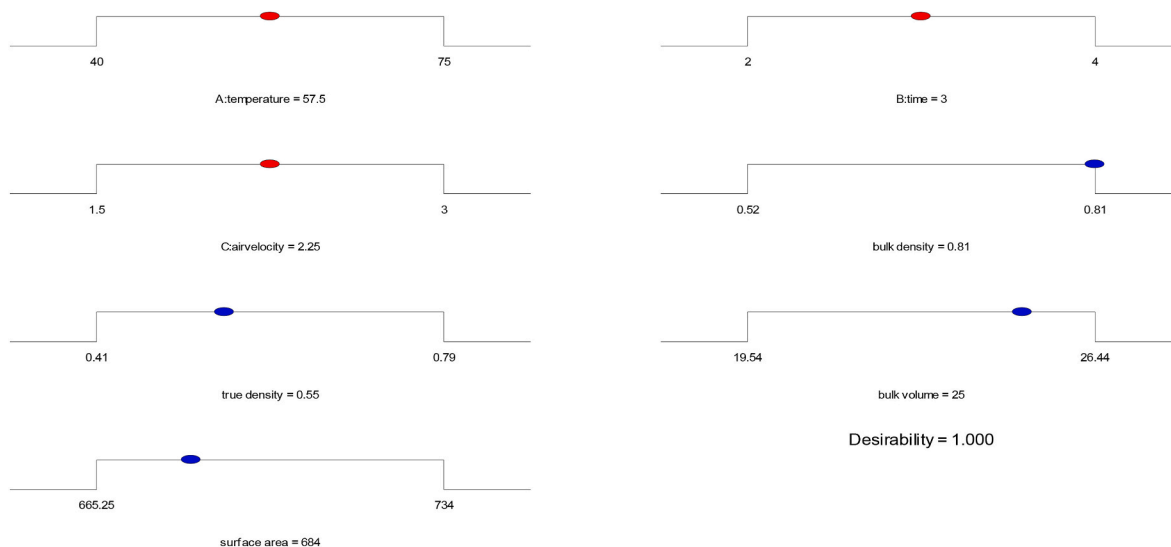


Fig. 8. Optimum Conditions for TLYS engineering properties.

Table 9

Performance of different ANN models in estimation of TLYS starch engineering properties.

Algorithm	M.S.E.	R^2
Levenberg-Marquardt	2.23487E-8	9.99999E-1
Bayesian regularization	2.5465E-9	9.99999E-1
Scaled Conjugate Gradient	3.63503E-0	9.99980E-1

Here no outlier was observed in the obtained work, this observation corroborates with the findings of [44] on the a designed experiment for CdS–AgBr photocatalyst toward methylene blue and [45] on a study on the enhancement and optimization of photocatalytic activity of ZnS and SnS₂.

The optimization of the bulk density, true density, bulk volume, and

surface area of TLYS physical/engineering properties was done using the optimization tool of Response Surface Methodology (RSM) and presented in Fig. 8; the optimal predicted bulk density of 0.81, true density (0.55), bulk volume (25) and surface area (684) was obtained at a temperature of 57.5 °C, time of 3 h and air velocity of 2.25 m/s with desirability of 1; Earlier researchers asserted that the closer the desirability value close to 1, the better the optimality of the process [3,47], also the information on the desired optimal responses for TLYS starch corroborates with the findings of [48] on the functional properties of wheat, cocoyam, and Bambara flour.

3.10. ANN model simulation for TLYS starch engineering properties

The ANN (MIMO) model was developed based on the feed-forward, backpropagation (B.P.) algorithms to predict TLYS engineering

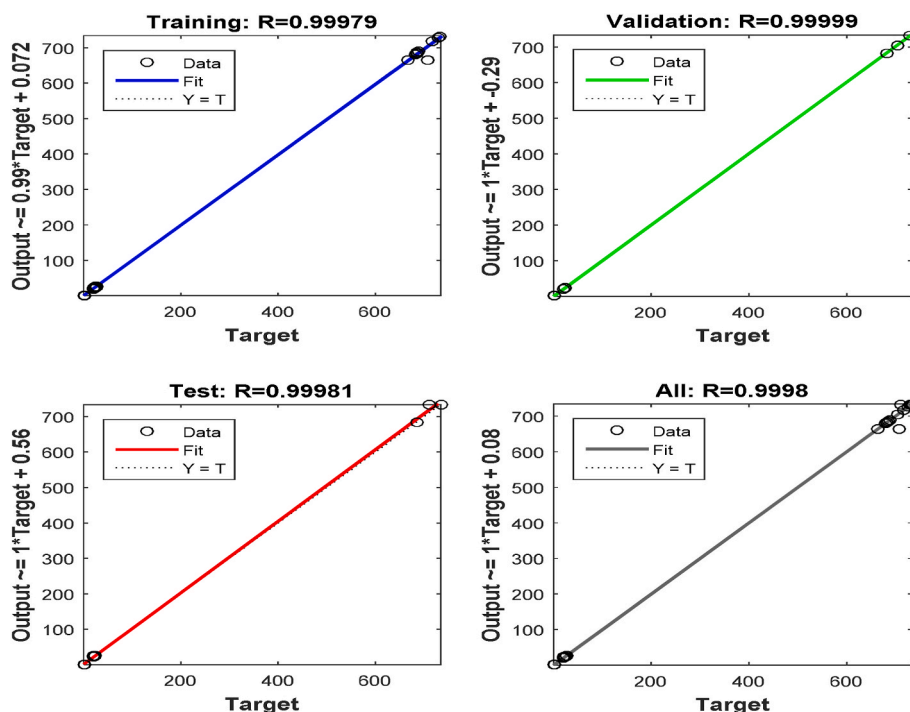


Fig. 9. ANN regression graph for TLYS engineering properties.

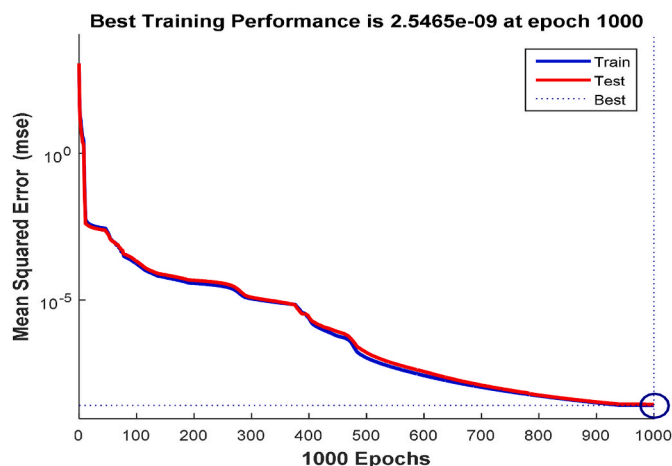


Fig. 10. Mean squared error for TLYS engineering properties.

properties. The hidden layer comprises ten neurons. As shown in Table 9, the Bayesian regularization was the best of the algorithms for TLYS engineering properties prediction, having R^2 of 0.99999 validated in Fig. 9 and M.S.E. of $2.5465\text{E-}9$ trained for 1000 iterations with the optimal result obtained at 1000 as shown in Fig. 10. This indicates that the model predicted engineering properties (bulk density, true density, bulk volume, and surface area) appropriately; The effectiveness of the predicted ANN model results is in agreement with reports from Ref. [1] on the exergy soft computing prediction of three-leaved yam drying and [15] on Artificial neural network modeling of *luffa cylindrica* antioxidant yield.

4. Conclusion

The engineering properties of TLYS starch were evaluated at various temperatures. An increase in temperature decreased the angle of repose (glass) and increased AOR (metal), bulk density, true density, and surface area. S.E.M. and proximate analysis indicate that the TLYS contains starch. The evaluated engineering properties had a significant effect on the response. The ANOVA showed that R^2 for the responses is close to 1, indicating a close relationship between the experimental and predicted responses; the optimization results confirmed that the regression model is acceptable. ANN successfully implemented a multi-input multi-output (MIMO) technique in predicting the responses with an M.S.E. of $2.5465\text{E-}9$, which indicates that the M.S.E. is closer to zero. The successfully predicted engineering properties of TLYS starch will help enhance its post-harvest performance/operations. Despite the nutritional benefits of TLYS starch, it remains underutilized; this study will inform farmers on the relevance of growing TLYS on a large scale, such as boosting the economic growth of the country and employing labor, although there are still constraints; poor agricultural pricing policies, low access to agricultural credit, land tenure insecurity, land degradation, low and unstable investment in agricultural research, and poor market access and marketing efficiency, hence further recommendation is required in evaluating and optimizing the economic analysis of TLYS production.

Credit author's statement

Nwosu-obieogu Kenechi, Goodnews Christian, Nwankwo Ekeoma and Simeon Bright developed the concept for the work, data curation, methodology, and supervision; Emmanuel Oke applied the software, validated and reviewed the work; Allen Maureen and Ohabuike Gabriel funded and supervised the work; Ude Chiamaka, Simeon Bright and Nwosu-Obieogu Kenechi reported the work.

Declaration of competing interest

The authors declares no competing interest in this work.

Data availability

Data will be made available on request.

Acknowledgment

The author expresses gratitude to the workers at the unit operating laboratory, Chemical Engineering Department, Michael Okpara University of Agriculture, Umudike, who assisted with the relevant equipment needed for the engineering properties assessment.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jafr.2023.100746>.

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