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MORALITY BEFORE KNOWLEDGE

Evaluation and modelling the effect of size, surface area and moisture content on breaking characteristics of African mango nut

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ABSTRACT

Background: African mango nut is a valuable but underutilized forest product due to dearth of research. This study was conducted to evaluate and model the effect of size, surface area, and moisture content on breaking characteristics of African mango nut, for appropriate selection and development of the nut cracking machine to minimize seed damage, curb energy wastage, and improve the processing operation. **Method:** This study was carried out at African mango nut moisture content range of 15–20% wet basis using standard methodologies from literature. **Findings:** Results showed that breaking of African mango nut requires compressive strength ranging from 411.23–414.18 N/cm^2 for nut of sizes between 3.24–3.49 cm and surface areas varying from 8.66–11.11 cm^2. The values of the yield strength recorded during the force-deformation (compression) process followed the same trend. Also, the compressive strength was found to increase with increase in moisture content and the consequential effect of increasing the moisture content as from 15 to 20 % on compressive force is higher than the resultant impact noticed in increasing the size between 3.24 and 3.49 cm and the surface area between 8.66 and 11.11 cm^2. The linear models developed were statistically significant at $P < 0.05$ with coefficient of determination (R^2) of 0.9902 and 0.9730 for compressive and yield strengths, respectively. **Conclusions:** The findings contribute to sustainable nut processing practices and energy-efficient food production in tropical regions. It also shows that a good relationship exists between the dependent and independent variables studied. **Novelty/Originality of this article:** Farmers and processors of African mango seeds could, select, design and create, or assess the cracking/breaking contrivance with the developed model equations.

KEYWORDS: African mango nut; sustainable processing; energy efficiency; agro-processing technology.

1. Introduction

African mango (*Irvingia gabonensis*), also known as bush mango, wild mango, or dika nut is a plant innate to humid West African forests (World Conservation Monitoring Centre, 1998). Its fruits have greenish-yellow skin, string pulp, and a massive, stiff seed (National Research Council, 2008). They are different from common mango (*Mangifera indica*) (Iponga et al., 2018). The pulp and seed of African mango are used in Nigerian and

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Cameroonian cookery to brand native soups, juice, sauces, jelly, wine, flavouring, and jam (National Research Council, 2008). Like various humid fruits, its pulp is a very rich source of vitamin C and carotenoid antioxidants. More so, the pulp could also be used to formulate black dye for cloth colouring (Moloney et al., 1887). African mango shrub is used in native medicine. The leaves, roots, and particularly the bark (in paste form) are traditionally used in treating skin pain and scabs while its juice is used as a weight loss supplement (National Research Council, 2008).

African mango is a class of African plants in the genus *Irvingia*, occasionally identified by the communal terms' wild mango or bush mango. They bear eatable fruits and are specifically cherished for their fat-and protein-rich nuts. The fruits are frequently consumed freshly by human beings and some animals like goats, sheep, monkeys, gorillas, elephants and many others. Because it unsurprisingly and chiefly originated in parts of Africa, it is prevalently called African mango (Orwa et al., 2009). The fruits are processed into juice and wine (Akubor, 1996; Mateus-Reguengo et al., 2020) and jelly and fruit jam.

African Mango Extract is obtainable in liquid, capsule, and powder forms. Occasionally, it is mixed with other extracts from green tea, berries, and kelp and sold as supplements (Egras et al., 2011). The extract is supposed to constrain the development of fat cells, though further human research is required for clear confirmation (World Conservation Monitoring Centre, 1998). The seed coat/shell of the African mango are locally used as a biomass fuel source, and there is research need to harness the potential of this bioresource in this regard.

Notwithstanding the contributions of African mango to the economy of Nigeria, mechanization of its processing has received little attention. Processors of African mango use matchet or stones to break or crack the seed coats/nuts to extract the seeds. This often results in broken seeds and lower market value. Again, processing of African mango seeds through this means is labor-intensive and can be made to benefit considerably from simple mechanization (Bamiro et al., 1986). Timeliness of processing operation in seed extraction has been identified as a major factor that will increase the intensity of African mango seed production (Ojha & Michael, 2012). Hence, there is a necessity to mechanize African mango seed extraction process operation. The traditional extraction and processing method is tedious, causing fatigue and backache due to the longer hours required for careful hand breaking or cracking of the shells and extraction of the seeds from the broken shells if damage to the seeds is to be avoided (Bamgboye & Mofolasayo, 2006). Manual processing of African mango increases the production cost as extra man-hours is required for shell cracking and extraction operation. On the other hand, excessive seeds are inevitably damaged in addition to drudgeries and the boring nature of the work. It is therefore appropriate to study the engineering properties of African mango to obtain empirical data that engineers will use to develop an efficient machine that will be affordable and easy to maintain. The developed machine will alleviate the difficulties and inefficiencies associated with manual processing and thus, enhance the production and processing of African mango in Nigeria and other producing areas.

Knowledge of engineering properties of agricultural products is essential in designing sustainable and efficient postharvest systems. These properties are influenced by many factors, which moisture content and dimensions are integral part. Again, these properties are unique and affect the design of postharvest systems. As a result, researchers have over the years evaluated these properties for several crops including sunflower seeds (Li et al., 2024), cashew nut (Sudaryanto et al., 2024), *Camellia oleifera* fruit shell (Wei et al., 2023), African oil bean kernel (Dickson et al., 2023), arugula seed (Mirzabe et al., 2021), plum kernel (Sheikh et al., 2021), among many others. There are variations in the engineering properties and conditions of different biomaterials. Characteristic data of different sizes and surface areas of the African mango nut under different moisture conditions is very important for post-harvest and processing machine design and fabrication, as these are the important parameters for breaking/cracking of the seed coat and extracting the seeds without damage to the seeds. Unfortunately, such data is not available to engineers/fabricators of the processing machines or manufacturers of the machines to enable them to produce an efficient processing machine. The provision of African mango nut engineering properties data will serve as a good guide for a better understanding, design and fabrication of the cracking machine components.

Baryeh (2002) and Altuntas et al. (2005) revealed that most mechanical properties of grain seeds increase with increase in moisture content. The compressive force required to initiate grain kernel rupture decrease with the increase in moisture content. Thus, the deformation at the grain rupture increases as the moisture content increases (Davis & Zibokere, 2011; Sharanagat & Goswami, 2014). Studies have shown that the composition of agricultural materials such as moisture and dimension affect their strength properties (Henshaw, 2008; Igbozulike et al., 2025). This implies that agricultural materials' properties are dependent on these parameters. Thus, the objective of this research work is to evaluate and model the effect of size, surface area and moisture content on the cracking strength of the African mango nut.

Inefficient processing of agricultural products contributes significantly to postharvest losses and affects sustainable food systems. Postharvest losses have both economic and social consequences which are evident in the many challenges in sub-Saharan Africa. Any loss encountered by the farmers and processors of agricultural products reduces their economic gains. This directly affects the people and businesses involved and indirectly affects the national economic fortunes. The prevalence of poverty in many rural areas of sub-Saharan Africa is attributed to inefficient agricultural systems. One of the major poverty indices is hunger, and hunger is associated with many factors including inefficient agricultural practices from production to handling, processing to storage and packaging that result in product losses. With an efficient African bush mango processing, postharvest losses will be minimized. This will enhance the ability of rural communities to withstand shocks, harvest yield fluctuations and sustain food security over a reasonable period. In essence, it will aid the Sustainable Development Goal 2 zero hunger target by increasing food availability especially in rural areas.

On the other hand, hunger, which is a consequence of food insecurity, often leads to insecurity and restiveness in society. Hunger triggers off survival mode that breeds social vices. To combat hunger, efforts need to be intensified in boosting efficient food production and processing technologies. Reduction in postharvest has been identified as a critical pathway to reducing poverty and poor nutrition (Strecker et al., 2022).

The processing efficiency of African bush mango needs to be improved to reduce postharvest losses, promote sustainable agricultural development and integration of the crop's circular bioeconomy. Optimization of the breaking characteristics will lead to minimized waste which is a key component of circular bioeconomy. Similarly, the improved processing will lead to improvement in the farmers' economy, reduction of total cost of postharvest operation, and increased product yield that will guarantee overall profitability of African bush mango. So, evaluating and modelling the effect of size, surface area and moisture content on breaking characteristics of African mango nut will promote sustainable food systems with the efficient processing of the crop and improved circular bioeconomy.

2. Methods

2.1 Experimental samples and apparatus used for the study

The experimental samples (Figure 1) include bulk fresh fruits of African mango (*Irvingia gabonensis*) obtained from Ogbete market in Enugu North Local Government Council of Enugu State, Nigeria. The apparatus used for the study includes an Electric Oven of Model n30c Gen Lab Wideness for determining the moisture content of the samples, an electronic weighing balance that has 0.001g sensitivity measuring the weight of the samples during the tests, and Testometric Universal Testing Machine with Load cell of 500 N and accuracy of 0.5 N sensitivity for the compression test.

Fig. 1. Samples of African mango fruits under study

2.2 Sample preparation

The bulk sample of fresh fruits of African mango (*Irvingia gabonensis*) was kept inside sacks to facilitate the decomposition of the fruits' pericarp and easy removal of the nuts. Thereafter, the nuts were removed manually, carefully cleaned with water and sun dried to low moisture level (Idowu et al., 2018). The samples were divided into three portions labelled A, B, C, and conditioned to three different moisture contents at room temperature of 26.4°C. Then, they were sealed separately in labelled polyethylene bags and kept in ambient condition for 24 h to equilibrate.

2.3 Determination of African mango nut samples

The oven dry method was used to determine the moisture content of sample (Aviara et al., 2012; Idowu et al., 2018) and evaluated using Equation 1 (Oduma et al., 2023). The symbols used in the formulas are defined as follows: Mc denotes moisture content (%). Ww denotes wet weight of the mango sample (g). Dw denotes dry weight of the mango sample .

$$M_c = \frac{W_w - D_w}{D_w} \times 100\% \quad \text{(Eq. 1)}$$

The dimensions of the randomly selected mango samples were measured at different moisture contents of 10%, 15% and 20% (w.b) using a vernier caliper of 0.001mm accuracy. The three dimensions (length, breadth, and thickness) were determined and the values obtained were used to evaluate the geometric size of the samples using Equation 2 (Igbozulike & Amamgbo, 2019). From the formula above, it can be seen that a refers to length (mm), b denotes breadth (mm), and c denotes thickness (mm).

$$Geometric\ dimension = (abc)^{\frac{1}{3}} \quad \text{(Eq. 2)}$$

The surface area of the African mango nut was determined from Equation 3, Gareth and Brother as adopted by Oduma et al. (2013). The symbols used in the formulas; A denotes the surface area of the mango nut (mm^2) and D refers to the thickness of the mango nut (mm).

$$A = \frac{\pi D^2}{4} \quad \text{(Eq. 3)}$$

The quasi-static parallel plate tests were performed using the Testometric Universal Testing Machine to determine the force-deformation characteristics along the length, breath and thickness axes of the nuts at two moisture content levels of 15% and 20% (wet basis). African mango nuts whose sizes and surface areas were already determined were placed individually using a laboratory tong on the compression jaws or grips, ensuring that the centre of the tool was in alignment with the peak of the curvature of the mango nut. Force was applied by turning the load arm of the testing machine at the speed of 3mm/min and the nut loaded to the point of rupture. This was accompanied by the corresponding drop of the force-deformation graph displayed in the computer attached to the machine, recording the force and the corresponding deformation. The mango nuts were deformed to the seed coat rupture under compressive loading. Yield strength was determined at the yield points at different loading positions and moisture content levels. The compressive strength of the nut was computed using Equation 4 (Sarajeh et al., 2014). From the formula above, Yc refers to compressive strength (Nmm-2), Fc refers to maximum load at fracture (N), and A refers to cross sectional area of specimen (mm^2).

$$Y_c = \frac{F_c}{A} \quad \text{(Eq. 4)}$$

2.4 Experimental design

The experiment consists of three factors, of which two (size and surface area) were varied at three levels which include 3.24, 3.42, 3.49 cm for size and surface areas of 8.66, 10.99 and 11.11cm^2, while moisture content was varied at two levels of 15 and 20 %. Central Composite Response Design was conducted for every trial using Equation 5 (Umani et al., 2019).

$$N = 2k + 2^k + nc \quad \text{(Eq. 5)}$$

From the formula above, N refers to number of test runs, k refers to experimental factors, and nc refers to centre point. To obtain the desired statistics, the array of figures for each of the three factors (k) was assessed as recorded in Table 1. Size, surface area, and moisture content were espoused as independent factors for the breaking force requirement of the African mango nut. The responses selected were the compressive strength, (N/mm^2) and yield strength, (N/mm^2). Four replications of the center points were espoused to calculate a fit and succinct estimate of errors; the research was carried out in randomized form.

Table 1. Actual values, codes and levels of the test variables for design of experiments

Factors	Symbols	Codes and levels		
		-1	0	1
Size, cm	Z	3.24	3.42	3.49
Surface area, cm^2	S	8.66	10.99	11.11
Moisture contents, %	M	15	-	20

2.4.1 Experimental design version 6.0

The Design Expert of version 6.0 was used to analyze the data obtained, optimize the practical factors espoused in the study of the effect of size, surface area and moisture content on the compressive and yield strength of African mango nut, and obtain empirical models for the estimation of the cracking/breaking strength of the mango nuts. The quadratic, cubic, linear and two factorial interaction (2F1) models were designated to analyze the compressive and yield strength of the shell/nut; and the models were fixed to the generated experimental data. Data obtained were analyzed using the Response Surface Methodology (RSM) to fit the quadratic polynomial equation gotten from the Design Expert Software as expressed in Equation 6 (Chih et al., 2010).

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{1}^{2} \beta_{ii} {X_i}^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j \quad \text{(Eq. 6)}$$

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The symbols used in the formulas, Y denotes Response, β_0 denotes constant term, $\sum_{i=1}^{2}\beta i$ denotes summation of coefficient of linear terms, $\sum_{i=1}^{2}\beta ii$ denotes summation of quadratic terms, $\sum_{i=1}^{2}\sum_{j=i+1}^{2}\beta ij$ denotes summation of coefficient of interaction terms, and $XiXj$ denotes independent variables. Also, the multiple regressions were adopted to fit the coefficient of the polynomial model to enable the response variables to be correlated with the independent variables. The reliability of fit of the model, the discrete and interaction effect of the parameters (size, surface area, and moisture contents) on the responses (compressive strength and yield point) of the African mango were evaluated using analysis of variance (ANOVA) with a significance level set at $p < 0.05$ using Minitab 17.0.

3. Results and Discussion

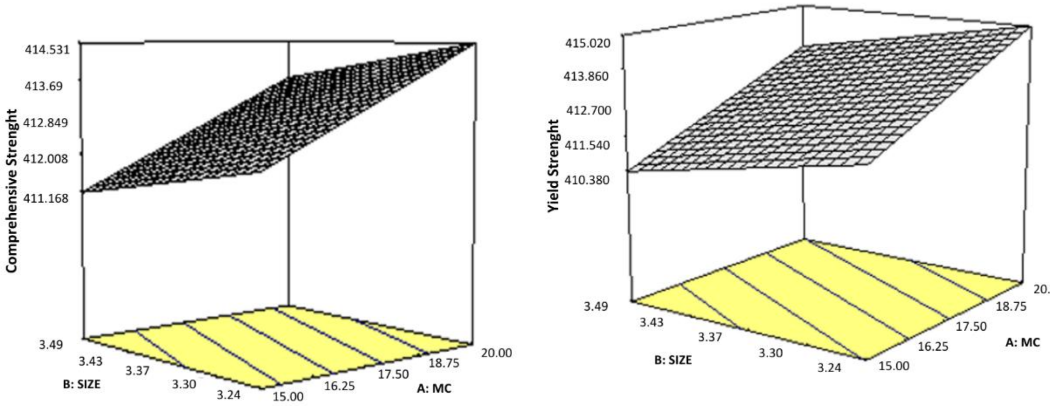
3.1 Breaking process of the African mango nut

The breaking process was accomplished at selected moisture contents (15 - 20 %) with designated sizes (3.24, 3.42 and 3.49 cm) and surface areas of 8.66, 10.99 and 11.11cm^2, and the results of the compressive strength and yield strength of African mango nut are presented in Table 2. The results showed that, breaking of African mango nut requires compressive strength ranging from 411.23–414.18 N/cm^2 for nut of sizes between 3.24–3.49 cm; and surface areas varying from 8.66–11.11cm^2 under the moisture contents investigated. Irrespective of size and surface area, the higher compressive strengths were obtained when the nuts were compressed at 20% moisture content level, while lower compressive strengths were observed at 15% moisture content level. This is evidence that the compressive force required to initiate nut cracking of African mango increases with the increase in moisture content.

Table 2. Actual and predicted values of compressive and yield strength of African mango nut

Factors				Compressive Strength (N/cm^2)		Yield strength (N/cm^2)	
S/N	Moisture content (%)	Average Size (cm)	Average Surface Area (cm^2)	Actual values of compressive strength	Predicted values of compressive strength	Actual values of yield strength	Predicted values of yield strength
1	15	3.24	11.11	412.15	412.16	412.15	411.18
2	15	3.49	11.11	411.23	410.59	415.26	410.74
3	15	3.49	10.99	411.23	410.57	415.26	410.71
4	15	3.49	11.11	412.15	410.59	411.15	410.74
5	15	3.49	8.66	411.23	410.19	415.26	410.25
6	20	3.42	8.66	413.63	413.70	413.63	413.69
7	20	3.42	11.11	414.18	414.10	414.18	414.18
8	20	3.49	11.11	413.63	413.66	413.63	413.74

This follows the pattern obtained by Simonyan et al. (2014), Sharanagat & Goswani (2014) and Davis & Zibokere (2011). The compressive strength obtained in this research work is slightly higher than the compressive strength achieved by Idowu et al. (2018) for bush mango nuts and this could possibly be because of fruit composition and variety. The compressive strength required to break African mango nut increases by 0.72% at moisture content varying from 15 to 20% irrespective of the size and surface area of the nuts. In general, compressive strength of African mango nuts increases with the increase in moisture contents. Similarly, the values of the yield strength recorded during the force-deformation (compression) process followed the same trend, for nuts of sizes between 3.24–3.49 cm and surface areas varying from 8.66–11.11cm^2 under the studied moisture contents. This is also consistent with the trend of findings of Simonyan et al. (2014) in their study of the effect of moisture content and loading orientation on some mechanical behaviour of Irvingian wombulu nut, where they noticed that under both lateral and longitudinal loading, the compression energy and unit volume energy increased with the increase in moisture content. However, the yield strength obtained in this research is slightly higher than that of Idowu et al. (2018) which might be attributed to loss of turgor pressure and chemical changes in the cell wall due to cell separation (Shomer, 1995). Figure 2(a) displays the response surface plot of size, surface area and moisture content against compressive strength of the mango nut presenting the relationship amongst the factors and the response (compressive strength).



(a) (b)

Fig. 2 (a) Response surface plot of size and moisture content against the compressive strength of mango nut; (b) Response surface plot of size and moisture content against the yield strength of mango nut

Results as displayed in the figure indicated that the compressive strength increases with the increase in moisture contents and that the consequential effect of increasing the moisture contents as from 20 % on compressive force is higher than the resultant impact noticed in increasing the size between 3.24 and 3.49 cm and the surface area between 8.66 and 11.11 cm^2. Figure 2(b) shows the response surface plot of size, surface area and moisture content against yield point of the mango nut indicating the correlation between the factors and the response. Results of this figure revealed that the highest yield strength of 414.18 N/cm^2 was achieved when the nut was compressed at a corresponding compression strength of 414.18 N/cm^2 at moisture content of 20%, average size and surface area of 3.42cm and 11.11cm^2 respectively. The highest yield strength attained at equal compression strength and at highest moisture content level (20%) is evidence that breaking of the mango nuts requires higher force of compression as the moisture content level increases and agrees with the observations of Davis & Zibokere (2011) and Seifi & Aliardani (2010).

The knowledge of compressive strength and yield point of African bush mango will help machine designers to avoid overdesign. Overdesign increases mass and inertia, lowers dynamic responses and raises loads in machine (Outokumpu Stainless, 2013). This is because the larger, heavier, or stronger components than necessary for the machine required loads will lead to increased mass which will in turn result in higher resistance in rotating parts. Also, a processing machine with higher mass and inertia responds slowly to dynamics in load and speed. These heavier components will exert more static and dynamic forces on bearings leading to frequent wear and reduction in the bearing life. So, the overarching consequence of this is that more energy than necessary will be needed to overcome inertia. The performance and efficiency of the machine will be negatively impacted.

According to Nyorere & Iweka (2019), mechanical damage due to impact or compression can occur during processing and the effect will show immediately or later during storage. Appropriate machine design with the empirical data on strength properties of African bush mango will help in preventing mechanical damage to the crop. Mechanical damage directly affects quality and economic status of the crop (Nyorere & Iweka, 2019).

Mechanical losses due to mechanical damage result from inefficient processing machines designed without adequate knowledge of the mechanical properties of crops (Shitanda et al., 2002). Efficient agricultural machines increase productivity (Antonio et al., 2018), boost farm income by 70% (Abebe et al., 2025) and improve the economic development for small scale farmers (Mada & Mahai, 2013). It also reduces the likelihood of food insecurity by 51% (Abebe et al., 2025).

3.2 Model equation of compressive strength and yield strength of African mango nut

The compressive strength requirement of the African mango nut is reliant on the results displaying significant difference of the breaking indicators. The contributions, effects, coefficient of model terms, lack of-fit test and significance of the factors and interactions on the compressive strength were examined according to Fakayode et al. (2017) and Umani et al. (2019). A linear model ensued significantly for the response ($P < 0.05$), inferring that the model term may possibly be noted at 95% level of significant (Table 3).

Table 3. ANOVA of model summary statistics for compressive strength

Source	Std. Dev.	R-Square	Adjusted R^2	Predicted R^2	PRESS
Linear	0.17	0.9902	0.9829	0.9309	0.82 Suggested
2FI	0.046	0.9996	0.9988	-	Aliased
Quadratic	0.057	0.9997	0.9981	-	Aliased
Cubic	-	-	-	-	Aliased

The linear model obtained to predict the compressive strength requirement with respect to the independent variables or functional operating parameters (moisture content, size, and surface area) is presented in Equation 7.

$$Cs = 421.48 + 0.6136\,M - 6.28\,Z + 0.1644\,S \qquad \text{(Eq. 7)}$$

From the formula above, C_S refers to compressive strength (N/cm^2), M denotes moisture contents (%), Z denotes size (cm), and S denotes surface area (cm^2). From Table 4, the p-value of the model term is 0.0002 which is below α- level of 0., implying that the indicators/factors have significant effects on the compressive force requirement of the nut.

Table 4. ANOVA of response surface linear model for compressive strength requirement of African mango nut

Source	SS	DF	MS	F VALUE	P>F	Remark
Model	11.71	3	3.90	135.00	0.0002	Significant
M	11.00	1	11.00	380.43	< 0.0001	Significant
Z	0.71	1	0.71	24.51	0.0078	Significant
S	0.041	1	0.041	1.41	0.3001	Significant
Residual	0.12	4	0.029	-	-	Significant
Lack of Fit	0.11	3	0.038	11.72	0.2108	Not significant
Pure Error	3.200E-003	1	-	-	-	Not significant
Cor Total	11.83	7	-	-	-	Not significant

Hence, the factors (moisture contents and size) have a major influence on compressive strength of the mango nut. In this case, moisture content and size of the African mango nut are significant model terms while surface area has no significant effect on compression strength of African mango nut ($P > 0.05$). This is consistent with the findings of Ehiem and Simonyan (2012) and Simonyan et al. (2014). Similarly, the yield strength requirement of the African mango nut is correspondingly dependent on the results revealing the significant difference for combination of the average size, surface area and moisture content level of the nuts. The linear model was statistically significant for the response ($P < 0.05$) and therefore was proposed (Table 5). This infers that the significant model term was noted at 95% significance level.

$$Ys = 421.5 + 0.6\,M - 6.3\,Z + 0.2\,S \qquad \text{(Eq. 8)}$$

The linear model expression obtained to guesstimate the yield strength relating to the independent variables (size, surface area and moisture content) is as presented in Equation 8. From the formula above, YS refers to yield strength (cm^2/N), M, Z, and S are defined in Equation 7.

Table 5. ANOVA of Model Summary Statistics for Yield Strength

Source	Std Dev.	R-Square	Adjusted R^2	Predicted R^2	PRESS
Linear	0.37	0.9730	0.9528	0.9425	1.14 Suggested
2FI	0.51	0.9739	0.9085	-	Aliased
Quadratic	0.63	0.9801	0.8604	-	Aliased
Cubic	-	-	-	-	Aliased

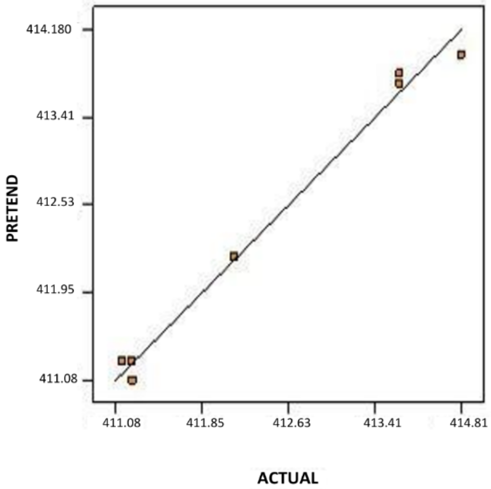
The model p-value of 0.0014 (Table 6) is lower than the selected α- level of 0.05 indicating that the model is statistically significant. Thus, the model term p-values of 0.0003 and 0.0170 which are less than the selected α - level of 0.05 stipulate that the model expressions are significant. As a result, moisture content and size of African mango nut are significant model terms according to Table 6 which is in line with the findings of Ehiem & Simonyan (2012).

Table 6. ANOVA of response surface quadratic model for yield strength of African mango nut

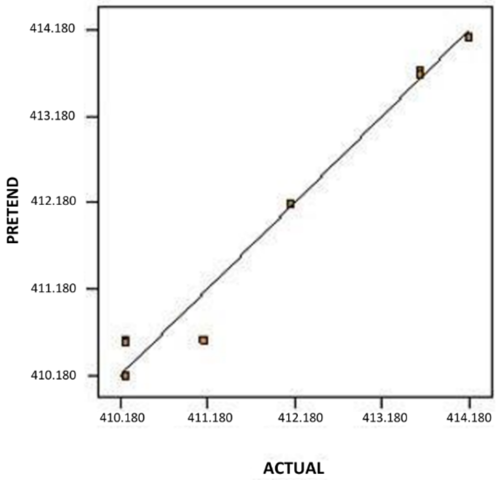
Source	SS	DF	MS	F Value	P>F	Remarks
Model	19.33	3	6.44	48.10	0.0014	Significant
M	17.31	1	17.31	129.19	0.0003	Significant
Z	2.08	1	2.08	15.52	0.0170	Significant
S	0.23	1	0.23	1.74	0.2581	Significant
Residual	0.54	4	0.13	-	-	Significant
Lack of Fit	0.14	3	0.047	0.12	-	Not significant
Pure Error	0.40	1	0.40	-	-	Not significant
Cor Total	19.87	7	-	-	-	Not significant

3.3 Model validation of compressive strength and yield point of the African mango nut

Figure 3 shows the validation of the suitability of the order linear model using the normal % probability plot of the breaking force demand residuals as well as the plot of the predicted versus experimental breaking force demand for compressive strength and yield strength of African mango nut. The plotted points fitted amply on the line of best fit which specifies that the predicted and experimental or actual compressive strength and yield strength are within acceptable array. The model equations broadly did not over or under-predict experimental results, thus, the predictions are within suitable array, an indication of good interactions and adequate correlation among the independent variables and a sign showing that the response model of the cracking force might define the general variableness in the response.



(a)



(b)

Fig. 3 (a) Normal % probability plot of the breaking force requirements residuals as well as the plot of the predicted versus experimental compressive strength of Africa mango nut; (b) Normal % probability plot of the breaking force requirements residuals as well as the plot of the predicted versus experimental yield strength of Africa mango nut.

Similarly, the result of Table 7 is another proof of the authentication of the developed models. Results revealed that the model is significant with coefficient of determination, R^2 of 0.9902 for compressive strength and 0.9730 for yield strength, which displays fabulous relations between the independent variables.

Table 7. Model summary statistics/validation of the model terms

Validation Instruments	Validation values	
	Compressive strength	Yield strength
R^2	0.9902	0.9730
Adj R-Squared	0.9829	0.9528
Pred R-Squared	0.9309	0.9425
Adeq Precision	23.883	15.119
PRESS	0.82	1.14

This is an indication that the response models can clarify 99 and 97% of the total erraticism in the responses for compressive strength and yield strength respectively (Umani et al., 2019). The simulation of the attained models indicated that the responses are within the experimental range. The predicted R^2 of 0.9309 is unswerving with the adjusted R^2 of 0.9829 for compressive strength and the predicted R^2 of 0.9425 is consistent with the adjusted R^2 of 0.9528 for yield strength of the mango nut, i.e. the differences are less than 0.2 suggesting that the trial data fitted very well. The adequacy precision ratio of 23.883 as recorded by the compressive strength and 15.119 recorded by yield strength is greater than 4, is desirable, suggesting an acceptable indicator and that the models might be espoused to circumnavigate the design space. Optimization of agricultural machine operations improves energy use efficiency (Jensen et al., 2025). The empirical data on the strength characteristics of African bush mango will help in understanding the stress-strain relationship necessary to estimate the energy requirements while designing the processing machine. So, an improved machine efficiency lowers the energy consumption of the machine.

4. Conclusion

This study revealed that a compressive strength range of 411.23–414.18N/cm² is required to break African mango nuts of sizes ranging from 3.24-3.49 cm and surface areas ranging from 8.66-11.11cm² in the moisture content range of 15-20 %. Irrespective of the size and surface area, higher compressive strengths were obtained when the nuts were compressed at 20% moisture content level, while lower compressive strengths were observed at 15% moisture content level. This shows that the compressive force required to initiate the cracking of African mango nuts increases with the increase in moisture content. The values of the yield strength recorded during the force-deformation (compression) process followed the same trend, for the samples evaluated.

The results also indicate that compressive strength increases with the increase in moisture contents and that the consequential effect of increasing the moisture contents to 20 % on compressive force is higher than the resultant impact noticed in increasing the size and the surface area. The linear models obtained were statistically significant for the responses ($P < 0.05$) and therefore were suggested. The normal % probability plot of the breaking force requirements residuals as well as the plot of the predicted versus experimental values showed that the plotted points fitted amply on the line of best fit. The means that the predicted and experimental or actual compressive strength and yield strength are within acceptable array. With good coefficient of determination (R^2) of 0.9902 and 0.9730 for compressive and yield strengths, respectively the models can clarify 99 and 97% of the total erraticism in the responses for compressive and yield strengths of African mango nuts.

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