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Design and Development of a Manual Pineapple Processing Machine Capable of Peeling, Coring and Slicing Pineapples for Small and Medium Enterprises

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ABSTRACT: Pineapple processing involves peeling, coring and slicing of pineapple. A simple manual pineapple processing machine was developed to enhance the crude method of processing pineapple using just the knife and to reduce musculoskeletal problems associated with processing large quantity of pineapples with the knife. Hence, the objective of this paper is to design and develop a manual pineapple processing machine capable of peeling, coring and slicing pineapples to be utilized by small and medium enterprises (SME) using Response Surface Method (RSM) and validated using desirability plots. The results of actual and predicted response surface plots confirms pineapple sample weight 1.35 kg, diameter 60, height 110 mm with efficiency of 94.81% as the optimal variables. The desirability plot validated these results with response of 1.47, 0.17, 0.06, 0.22 kg weights of peeled, peel and core of pineapple removed, respectively, machine peeling efficiency at 87.29 % as optimal at 11 seconds. At these optimal conditions, the actual efficiency realized was 94.81 %. The differences within the actual and predicted valuations were lower and not significant statistically, which implied that selected model efficiently predicted the peeling efficiency of the machine. Center Composite Design Rotatable (CCDR) was employed to initiate 20 experimental processes.

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Pineapple *(Ananas comosus* L. Merr) is located mostly in all the tropics and subtropics region worldwide and its ranked 3rd in fruits cultivation in the tropics (Paull and Duarte 2019). Pineapple is commonly sown mainly for its fruits, which is sometimes eaten fresh or processed into juice or and persevered (Adinya *et al.* 2010). To process pineapple, one has to start with the task peeling (manually) which can be repetitive, time consuming, laborious and breeds drudgery especially when producing in large quantities (Kumawat and Raheman, 2022). Peeling pineapple involves removal of outer skin of pineapple which is thick and hard to remove (Oliveira and Vitória, 2011). While coring is removal of the center tough structural fiber of the pineapple, while the content between peel and the core of the pineapple is referred to as the pulp (Shinde *et al.*

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2017). Joy, (2013) postulated that pineapple peeling (processing) consumes time and energy during the operation which usually lead to muscularity drudgery.

However, various types of devices have been developed for coring, peeling and slicing of pineapples. Singh *et al*. (2013) designed and advanced a hand pineapple peeling-cum-slicing device. Similarly, Ankit *et al*. (2023) designed a hand operated pineapple peeling machine that removes the pineapple core, reported to have worked satisfactorily. This study focused on design and improvement of a simple hand, cost effective pineapple peeling, coring and slicing mechanism for SME's. Hence, the objective of this paper is to design and develop a manual pineapple processing machine capable of peeling, coring and slicing pineapples to be utilized by small and medium enterprises (SME).

MATERIALS AND METHOD

Materials: Materials utilized in this study was Cayenne pineapple cultivar gotten from the National Horticultural Research Institute Oyo state, Nigeria (NIHORT). Stainless steel selected for the construction of the pineapple peeling, coring and slicing machine was purchased at Agodi Gate market Ibadan, Oyo state Nigeria. Other materials include; bolt and nut, sensitive scale, measuring tape and a stainless steel knife etc.

Design Considerations: Materials utilized in this study design were carefully chosen centered on these properties: strength of the materials, resistance to corrosion, durability, stability, simplicity, rigidity, cost effectiveness, power requirement of the machine and the physical parameters of the pineapples. Other parameters considered in the design of the machine included; the dimension of the machine for easy operation, thickness and sharpness of the helical cutting edge and the diameter of coring cylinder.

Functional Requirement

Determination of Shaft Diameter: The cutting Shaft inner and outer diameters were obtained from the torsional equation given in Equations 1 and 2 calculated to be 30 and 70 mm, respectively (Khurmi and Gupta, 2005; Song, 2022). However, the outer diameter of the cutting shaft is assumed to be the diameter of the helix.

$$d_o = \left[\frac{16T}{\pi \tau_d}\left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}} \qquad (1)$$

Where, d_o = diameter outer hollow shaft (mm), d_i = diameter inner hollow shaft (mm), $K = \frac{d_i}{d_o}$ = inner to outer diameter ratio of hollow shaft, T = the torque transmitted (Nmm), τ_d = design shear stress (MPa).

Torsional moment of shaft: Since the handle of the pineapple machine is subjected to twisting moment, then, the maximum shear stress (tensile or compressive) was obtained from Equation 2 calculated to be 0.133 Mpa (Song, 2022).

$$\tau_{\max} = \frac{2TR}{\pi(R^4-r^4)} = \frac{16TD}{\pi(D^4-d^4)} \qquad (2)$$

τ_{max} = maximum shear stress, T= torque action on shaft, R = radius of outer shaft, r = radius of inner shaft, D diameter of outer shaft, d = inner shaft diameter a factor for normal stress (tensile or bending).

Angle of twist on shaft: Twist angle of the shaft was gotten by using Equation 3, (Song, 2022) which informed the angle of the attachment of the serrated helical cutter and slicer of pineapple pulp calculated to give 4.48 rad.

$$\text{Twist angle; } \theta = \frac{TL}{GJ} \text{ (rad)} \qquad (3)$$

Where; L = shaft length (mm), G = shaft material's shear modulus of elasticity (hollow stainless steel) (mm^4)

Shear stress of torsion: The Shear stress of torsion (S_s) of pineapple machine was calculated to be 1.94 Nmm^{-2} and Polar moment of inertia (J) = 2.277E^6 kg/mm using Equations 4 and 5, respectively. (Song, 2022)
Shear stress of torsion;

$$S_s = \frac{Tc}{J} \qquad (4)$$

$$J = \frac{\pi}{32}\left(d_o^4 - d_1^4\right) \qquad (5)$$

Where; c = shaft radius, J = inertia polar moment kg/mm

Description of pineapple machine component: Components of the fabricated pineapple peeling, coring and slicing machine consists majorly of the *Main shaft* 280 mm in height and 30 mm diameter hollow cylindrical stainless steel (shaft). The bottom end of the shaft is serrated 2 mm deep into the shaft to function as the corer. The *Stainless steel handle* made from a cylindrical stainless steel material, 180 mm in length and 30 mm diameter welded to the main shaft for easy twisting by hand. An *M10 bolt and nut* were welded to the cylindrical handle and centralized and screwed to the main shaft of the pineapple processing machine. A *stainless steel plate* of 0.1 mm thickness and 40 mm diameter sharpened at the edges was used to prepare the helical slicing disc welded to the main cutting shaft.

Operational procedures: The crown of the pineapple was firstly cut 6 mm below the leaves with a knife. The pineapple was then put uprightly on a flat surface bottom up with machine placed over the pineapple then centered at the core, The peeling, slicing and coring is then accomplished by pressing and twisting the cutting shaft over the pineapple which initiates the peeling, cutting, coring and slicing operations simultaneously. Concurrently, the pineapple core is cut by the serrated hollow cylindrical main shaft; however the cut off pineapple core fills the hollows of the cylindrical as the processing operation proceeds.

Performance evaluation of peeling machine: This study used rotational central composite design of response surface to design, evaluate and optimize the processing considerations for the designed manual pineapple peeling, coring and slicing machine.

Peeling efficiency: Each sample of the de-crowned unpeeled pineapple was weighed before been subjected to peeling, coring and slicing processing by pineapple machine. Weights of peeled, core and pineapple removed (peel + core) (kg) were observed and recorded. Machine peeling efficiency percentage was calculated using equation (6), (Gbabo *et al*., 2013; Adeshina and Olusola, 2020) as given in equation 6:

$$MPE = \frac{WPP}{WUPP} \times 100 \quad (6)$$

WPP = weight of peeled pineapple (kg); WUPP = weight of unpeeled pineapple (kg).

Experimental design and optimization: The designed and fabricated pineapple machine' processing factors and effects were studied. A three factor rotational central composite design applying near rotatable Central Composite Design (CCD) model where $\alpha = \pm$ generating six center points and 20 experimental runs of Response Surface Methods (RSM) of Design-Expert 13.0.5.0 x 64 (Stat-Ease, Inc., 2021). This was used to optimize processing variables for a simple manual pineapple peeling, coring and slicing machine so as to complement the process efficiency of the pineapple machine ((Bajpai *et al*., 2012; Lakshminarayanan *et al*., 2015). The focus of the study is to come up with a model for predicting the efficiency of a pineapple processing machine and to actualize the optimal set of the process variables. Three process variables - weights of unpeeled (A), diameters (B) and heights (C) of the pineapple samples - were investigated are as indicated in Table 1. A complete regular second-order quadratic response surface model was then close-fitting to every of the responses.

Table 1. Independent Factors, Coded and Actual levels of Design of Experiment

S/N	Independent factors	Symbol	Unit	Code	Level		
					-1	0	+1
1	Weight of Pineapple	A	kg	X_1	1.35	1.93	2.50
2	Diameter	B	mm	X_2	60.00	70.00	80.00
3	Height	C	mm	X_3	110.00	170.00	230.00

The experimental design generated twenty (20) procedures at three independent variables for the experiment results were: weight of unpeeled pineapple at (1.35, 1.93 and 2.5) kg and their diameters (60, 70 and 80) mm, heights (110, 170 and 230) mm, respectively, in a quadratic factorial interaction design model. All factors were studied at low, center and high (-1, 0 and 1) levels, coded as X_1, X_2 and X_3 and the actual levels are as shown in Table 1. On the other hand, the weights of peeled, peel, core and removed (peel + core) of pineapple as well as the machine peeling time (seconds) and efficiency (%) response variables were applied to estimate the processing efficacy of the pineapple device, were all considered in the design of experiment. The outcomes data of complete quadratic model as shown in Table 5 were applied to estimate the machine process efficiency and analyzed with ANOVA.

Data Analysis: Response Surface approach was employed to improve capabilities of the processing mechanism, and was confirmed applying desirability plots which boosted processing efficiency of pineapple cultivar utilized. Quadratic regression model design with actual value terms were used in the prediction equation aimed at the interactions between independent factors and responses were developed and represented in general form in the experiment as expressed in Equation 7 (Myers *et al*., 2016; Ikrang *et al*., 2019; Morakinyo *et al.*, 2020).

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^3 \quad (7)$$

Where Y = predicted response variables; β_o is a constant coefficient; β_1, β_2 *and* β_3 are the linear coefficients; β_{11}, β_{22} *and* β_{33} are the quadratic coefficient, β_{12}, β_{13} *and* β_{23} are interaction Coefficients factors or variables 1, 2 and 3, while X_1, X_2 and X_3 are independent factors (un-coded).

The outcomes of performance of experiment were analyzed with Analysis of Variance (ANOVA). Still, statistical significant level was confirmed using F-test and adequate precision ratio, while means were separated at $p \leq 0.05$ level of significance to verify the adequacy of the close-fitted model. The validity of the regression representation was completed using coefficient of correlation (R^2), coefficient of determination (Adj-R^2) and Lack of Fit test. However, Desirability plots were applied to confirm the best run of response surface method (RSM) (Steven *et al*., 2009; Diana *et al*., 2019).

RESULTS AND DISCUSSION

The developed pineapple processing machine: Figure 1 shows the developed and fabricated pineapple peeling, coring and slicing machine. The differences recorded in the efficacy of the designed and the developed simple manual pineapple peeling, coring and slicing machine occurred as a result of the variations in the weights of pineapple done in triplicates; 1.35, 1.93 and 2.5 kg, diameters; 60, 70 and 80 mm, heights; 110, 170 and 230 mm and data from the experiment was fitted into a second order poly-nominal equation. However, the pineapple machine processing time was also noted to be between 10 and 11 seconds.

Performance Evaluation Result: Performance assessment outcomes of twenty (20) investigational runs of the pineapple processing device was based on interaction among the three independent factors at three levels and the equivalent responses as indicated in Table 3. The outcomes showed that the pineapple sample weight 1.35 kg, diameter 60, height 110 mm presented the highest efficiency of 94.81%. Comparable to the design of Singh *et al*. (2013) developed manual pineapple peeling cum slicing device that cuts off pineapple core and yields pineapple peels with a even diameter and thickness with one singular movement with an efficiency of 97.2%. Akin also to Abdul Vahid *et al*. (2013) designed manual pineapple processing machine which recorded an efficiency value ranging between 99-100 %.

Fig 1: Designed and fabricated manual pineapple processing machine

Effect of pineapple weight, diameter and height on the machine efficiency: The variations in the machine peeling efficiency at different operational runs are as indicated in Table 3. A decrease in the diameter of the pineapple led to a decrease in the weight of the pineapple peel resulting in an increase in the machine peeling efficiency. Table 5 reveals that diameter and weight of pineapple had significant resultant effects on the machine peeling efficiency, regardless of the height of the pineapple (Table 3).

This is also comparable to the observations of Singh *et al*. (2013) that the height of pineapple did not have significance on efficacy of pineapple peeler cum slicer. Similar to Ankit *et al*. (2023) developed pineapple peeling machine, which suggested that weight of pineapples contributes majorly to the efficiency of the machine.

However, Table 4 reveals the regression analysis of the quadratic model of the influence of the operative factors on peeling (processing) efficiency of the pineapple machine at $p \leq 0.05$ significant level. The machine peeling efficiency ranged between 79.20 and 94.81 %. A related pineapple processing device was also reported by Vidhu *et al*. (2002). Similarly, Kim (2006) patented a simple pineapple consisting of a single piece of hollow metal with a round peeling inner part and cutting outer part. Additionally, the pineapple peeling (processing) efficiency obtained in this study is identical to the outcome of Abdul Vahid *et al*. (2017). It stated that peeling efficiency of pineapple machine is not usually altered with respect to diameter and weight of pineapple. Also comparable to Shinde *et al*. (2017) designed pineapple peeler and coring machine which possesses two cylindrical blades to cut off pineapple core, skin, leaves and root, simultaneously. Whilst the one in this design peels, core and slices the pineapple. Additionally, Vishal *et al.* (2018) developed a manual peeling machine, where peeling is achieved by placing the bear fruits in-between rotating fruit hangers, hence peeling is done horizontally capacity 93kg/hr, while the design in this study calculated average capacity is 629.9kg/hr. Ankit *et al*. (2023) also designed a hand operated pineapple peeler-cum-slicer comparable to that of this study with peeling time 191s, the one in the study peeling time 10 to 11s.

Table 3. Results of the Experiment of Pineapple, Peeling, Coring and Slicing Operation

WUPP (kg)	Diameter (mm)	Height (kg)	WPP (kg)	WP (kg)	WPC (kg)	WPR (kg)	Time (s)	MPE (%)
1.93	70.00	170.00	1.63	0.22	0.06	0.28	11	84.46
1.35	80.00	230.00	1.24	0.11	0.07	0.11	10	91.85
1.35	60.00	110.00	1.28	0.05	0.02	0.07	10	94.81
2.5	60.00	110.00	1.98	0.44	0.08	0.52	10	79.20
1.93	86.82	170.00	1.67	0.19	0.07	0.26	11	86.53
1.93	70.00	170.00	1.66	0.21	0.06	0.27	12	86.01
2.89	70.00	170.00	2.58	0.50	0.09	0.31	10	89.27
1.35	60.00	230.00	1.22	0.08	0.05	0.13	11	90.37
2.50	80.00	110.00	2.00	0.43	0.07	0.5	11	80.00
1.93	70.00	170.00	1.66	0.20	0.07	0.27	11	86.01
1.93	70.00	170.00	1.67	0.18	0.08	0.26	11	86.53
1.93	70.00	170.00	1.70	0.18	0.05	0.23	10	88.08
2.50	60.00	230.00	1.70	1.07	0.08	1.15	10	68.00
1.93	70.00	69.09	1.64	0.16	0.06	0.10	10	84.97
1.93	70.00	270.91	1.70	0.19	0.04	0.23	11	88.08
0.96	70.00	170.00	0.78	0.13	0.05	0.18	10	81.25
1.93	53.18	170.00	1.67	0.22	0.04	0.26	11	86.53
2.50	80.00	230.00	2.00	0.44	0.06	0.50	11	80.00
1.35	80.00	110.00	1.22	0.10	0.03	0.13	10	90.37
1.93	70.00	170.00	1.65	0.22	0.06	0.28	11	85.49

WUPP = weight of unpeeled pineapple, weight of peeled pineapple, WPP = weight of peeled pineapple, WP = weight of peel, WPC = weight of core WPR = weight of pineapple removed (peel + core)

Model of the machine peeling efficiency: The fit simulation in this study for the peeling efficiency was specified contingent on the central-order polynomial that indicates significant terms and model are not named; non-significant lack of fit and highest level of *Predicted* R^2 and the *Adjusted* R^2 can used to predict the outcome of efficiency of the pineapple machine as revealed in Table 4 (Ikrang and Umani, (2019). Hence, Quadratic regression representation (model) was adopted to predict the peeling efficacy of this pineapple machine.

Equally, the *coefficient of determination* (R^2) (0.3797) Table 4 specified the relationship exiting amongst the independent variables, conversely, the model equation relating to coded variables could therefore be adopted to form predictions over the responses for the assumed figures of each variables. By defaulting, the higher variables are coded as $\alpha = +1$ while the lower levels coded as $\alpha = -1$ compensating for variation in the sizes of the pineapple samples used.

Coded equation is usually fit for distinguishing relatively the effect of the variables by likening the variable coefficients. This is a quadrangular regression model specifying all actual terms and values selected in the prediction equation as expressed in Equation 8.

Table 4. Regression Analysis Response Surface Quadratic

Regression Terms	**Quadratic Values**
R^2	0.3797
Adjusted R^2	-0.1786
Predicted R^2	-2.5983
Adequate Precision	2.9957
Std. Dev.	5.4800
Mean	87.0300
C.V. %	6.2900

Adequate Precision in design of experiment (DOE) records the signal to noise ratio of selected terms to other terms. Nevertheless, higher *predicted* R^2 figure could be achieved using reduced quadratic equation but with significant values. However, a ratio of 2.9957 in the regression analysis response surface quadratic obtained indicates that an inadequate signal may not be used in this model to navigate the design space, since the terms are not significantly related. In this case model reduction may not be required.

Further calculations revealed a *desirability level* (94.81 %) of the regression analysis as exposed using Equation 8 (Rastegar *et al*., 2011; Bajpai *et al*., 2012).

$$MPE = 85.37 - 1.73 + 2.08B - 0.6367\,C + 2.05AB + 0.0014AC - 0.7393BC + 0.2241A^2 + 1.61B^2 + 0.5804C^2 \quad (8)$$

Where: MPE = machine peeling efficiency; (A = WUP weight of pineapple, B = Diameter of pineapple, C = Height of pineapple) are linear terms (first-order), while A^2, B^2 and C^2 are quadratic terms (second-order); 94.81 = intercept coefficient (offset); AB = intercept between weight and diameter.

The ANOVA of machine peeling performance of pineapple cultivar is as shown in Table 5 which discloses that diameter and weight of pineapple had significant resultant effects on the machine peeling efficiency, regardless of the height of the pineapple (Table 3). This is comparable to the view of Singh *et al*. (2013) that the length (height) of the pineapple had no significant effect on the efficiency of pineapple peeler cum slicer; and Ankit *et al*. (2023) developed pineapple peeling machine which inferred that the weight of pineapple contributed to the efficiency of the machine. The analysis result of *model F-value* of 0.68 for the machine peeling efficiency indicates that the independent variables of the model are not significantly relative to noise (inferences). However, there is a likelihood that an *F-value* of 71.32 % could have occurred likely due to noise. Although, *P-values* <0.050 implies model variables are significant, in this situation the model variables are not significant; nonetheless, if the values obtained are >0.100, then the model variables are not significant. Then, if numerous non-significant models (not recognizing those needed to support hierarchy) occur then, reduction of model may improve it. Even so, the *F-value* of 2.33 gotten in *Lack of Fit* mean that *Lack of Fit* is non-significantly related to pure error. This implies that there exists an 18.69 % possibility that *an F-value* of *Lack of Fit* this large could have resulted from noise. A result of *lack of fit* not significant however is desirable.

Table 5. ANOVA Quadratic Model Machine Peeling Efficiency

Source	Sum of Squares	df	Mean Squares	F-Values	p-Values	
Model	183.50	9	20.39	0.68	0.7132	not significant
A-WUP	40.96	1	40.96	1.37	0.2696	
B-Diameter	58.82	1	58.82	1.96	0.1916	
C-Height	5.55	1	5.55	0.19	0.6762	
AB	33.73	1	33.73	1.12	0.3138	
AC	0.00	1	0.00	5.51E-07	0.9994	
BC	4.37	1	4.37	0.16	0.7105	
A^2	0.72	1	0.72	0.02	0.8796	
B^2	37.50	1	37.50	1.25	0.2896	
C^2	4.85	1	4.85	0.16	0.6959	
Residual	299.83	10	29.98			
Lack of Fit	209.89	5	41.98	2.33	0.1869	not significant
Pure Error	89.94	5	17.99			
Cor. Total	483.33	19				

Optimization and desirability model for machine peeling efficiency: There existed a notable acknowledgement relating the actual and predicted values for the peeling efficacy of the machine. Figure 2 indicates that the data obtained from the experiment fits accordingly with the model used in the study and shows a satisfactory ample assessment of responses for the pineapple processing in the scale of the factors used for the study. Desirability plotted solution of the optimum interaction obtained indicated optimum peeling variables and responses to be peeling efficiency (94.81 %), weight of unpeeled pineapple (1.35 kg), diameter (60 mm), weight of peeled pineapple (1.28 g), weight of pineapple peel (0.29kg), weight of core (0.02kg), weight of peel removed (peel + core) (0.07kg), at 10 seconds process time. Whilst, predicted optimum experimental responses ranged within 1.47 and 2 kg weight of peeled, 0.04 to 0.08 kg weight of core, 0.2 to 0.4 kg, weight of peel removed of the pineapple, respectively, with machine peeling efficiency at 87.29 % at 11 seconds process time with desirability of 1. The difference between the actual experiment results and the predicted values was lower and not significant statistically.

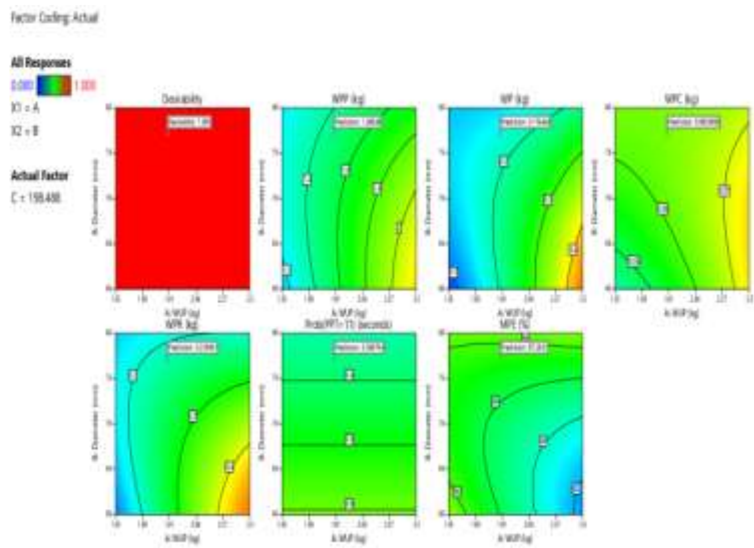

Fig 2: Desirability plot comparison at optimum predicted and actual values of peeling efficacy

Conclusion: Performance of the developed pineapple peeling, slicing and coring machine was satisfactory with the peeling efficiency result obtained. Diameter and weight of pineapple had significant resultant effects on the machine peeling efficiency, regardless of the height of the pineapple. The newly designed pineapple machine is suitable for SMEs and households. However, recommendation are made that other cutting edge with varying diameter be made attachable to the handle of the apparatus to peel pineapples as required (either smaller or larger) using readily sustainable material of construction.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the corresponding author

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