Computers and Electronics in Agriculture 177 (2020) 105715

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Modeling and optimization of developed cocoa beans extractor parameters using box behnken design and artificial neural network

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A R T I C L E I N F O

Keywords:
Cocoa bean extractor
Machine design
Efficiency
Capacity
Energy requirement

A B S T R A C T

Breaking the cocoa pod and extracting the beans is a strenuous and laborious task; hence an attempt was made to design and optimize a mechanized continuous cocoa beans extractor. Cocoa fruit was fed manually into a breaker unit through the hopper. The tangential force of the roller pushed the cocoa pod towards the gap resulted in breakage. The strainer attached with pod breaker separate the cocoa kernels from cocoa pod and placenta. The developed machine was tested and the parameters have been optimized by using box-behnken design (BBD) and artificial neural network (ANN). The input variables of bod breaker were roller speed (260, 360, and 460 rpm), cocoa pod size (140, 160, and 180 mm) and inclination angle of strainer (40, 45, and 50°) and out put variables involving capacity, machine efficiency, energy requirement, shelling efficiency, beans separation efficiency, and bean damage percentage.. The coefficient of determination (R2) of BBD ranged between 0.95 and 0.99, and the sum of squared error (SSE) ranged between 8.38 and 158.3, Whereas the R^2 of ANN ranged between 0.94 and 0.99, and mean squared error (MSE) ranged between 0.0013 and 0.0074. This indicates ANN design superior performance over BBD. The performance parameters of 360 rpm roller speed, 160 mm pod size and 45° inclination angle were determined as optimum conditions to obtain maximum capacity (626.8 kg/h), machine efficiency (96.78%), shelling efficiency (96.3%), beans separation efficiency (86.42%), and low energy requirement (10.54 kJ) with less beans damage percentage (< 1%).

1. Introduction

Cocoa is an excellent primary material for the manufacture of chocolates, cosmetics, health drinks, pharmaceuticals, etc. It contains about 50 percent fat, which is useful for producing a candle, ointments, pharmaceutical products, cosmetics, etc. (Porter, 2006; Prosapio and Norton, 2019). The cocoa pod is the best source for the creation of potash manure, soap, biogas, and speck boards (Babayemi et al., 2010; Adjin-Tetteh et al., 2018). The global needs for cocoa beans have been steadily increased over recent decades due to the increased consumption of chocolate and chocolate-flavored products (Sunoj et al., 2016).

At present, the cocoa pods have been broken manually using wood and machete. Thus, it is a strenuous and time-consuming process. The manual method of cocoa pod breaking leads to damages to the beans, increase the percentage of bean losses, and reduces the profit. The strenuous task causes the persistent weakness and sickness of the labor and farmer, resulting in a low standard of health (Huang et al., 2010; Patrício and Rieder, 2018).

The extensive requirement of labour during the manual method results in the high cost of production. Adewumi and Fatusin (2006) and Chamsing et al. (2006) have been developed a hand operated mechanical cocoa pod breaker. The automated method of extracting the cocoa beans will reduce fatigue for the farmers and the labours. Also, the losses usually occur during the manual breaking of the pods and separating beans from the placenta with wood, and cutlass will be reduced, which enhances income for the farmers. The time required for extracting the beans using the manual method will be reduced by the mechanical way (Kate et al., 2018).

The optimization of machine design conditions becomes a problem which has been vigorously analyzed as concern agriculture, biosystems,

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https://doi.org/10.1016/j.compag.2020.105715
Received 31 May 2020; Received in revised form 5 August 2020; Accepted 11 August 2020
0168-1699/ Published by Elsevier B.V.

and food processing industries pertained different devices and abilities were applied for this view in order to accomplish reasonable quality solutions (Sudha et al., 2016; Le Chau et al., 2019). BBD from Response Surface Methodology (RSM) can be depicted as an empirical modeling system and could be utilized for developing, improving, and optimizing complex processes (Madadlou et al., 2009; Chau et al., 2018; Chau et al., 2019). RSM has the advantage of decreasing the count of experimental runs, which is enough to furnish statistically acceptable results (Nourbakhsh et al., 2014). RSM used to optimize agricultural oriented machine design (Saldaña-Robles et al., 2020), post-harvest processing machine design (Sofu et al., 2016), food processing machine designs (Umani et al., 2019), dairy processing machine design (Madadlou et al., 2009), food product development optimization (Kothakota et al., 2013a, 2013b, 2016, 2017; Nagpal et al., 2018; Pandiselvam et al., 2019a), food process optimization (Santana et al., 2018; Sagarika et al., 2018; Shameena Beegum et al., 2019) and food preservation optimization (Nourbakhsh et al., 2014; Gaurh et al., 2017). Artificial neural network (ANN) have great learning capacity and potential of determining and modeling the complicated non-linear relationship among the input and the output of a system in comparison to RSM. ANN has appeared as an extra robust and excellent modeling tool, as a result of its ability to determine from observations and to draw conclusions using rationalization and predictive modeling from the behaviour of complex nonlinear method. Numerous investigations had stated on ANN applications for design and performance of the machine in agricultural processing (Saldaña-Robles et al., 2020), post-harvest processing of crops (Nourbakhsh et al., 2014; Santana et al., 2018), food storage (Sanaeifar et al., 2018), food preservation (Santana et al., 2018), dairy processing (Madadlou et al., 2009) and process optimization for product development (Nagpal et al., 2018; Pandiselvam et al., 2019a).

Considering the aforementioned factors, the post-harvest processing of cocoa has to be mechanized.. Hence, this present study aimed for 1) design and development of continuous cocoa beans extractor. 2) modeling and optimizing the machine performance parameters by applying BBD and RSM 3) cost analysis and field testing of a developed prototype in comparision with the manual process.

2. Materials and methods

2.1. Raw material

Matured cocoa fruits (*Theobroma cacao L.*) of two verities (*Criollo* and *Forastero*) were procured from M/s Cadbury unit of Kerala Agricultural University, Thrissur, India, and the progressive farmer from Karuvarakundu, Malappuram, India. The cocoa pods were cleaned and sorted from cracked, skin injuries, and disease affected pods. Moisture content of cocoa pod husk was determined by AOAC (2000) method. The experiment was carried out at fixed moisture 81.21 ± 1% wb (for *Criollo* veriety) and 79.45 ± 1% wb (for *Forastero* veriety).

2.2. Engineering properties

The physical properties (length, diameter, mass, size, shape, sphericity, volume, true density, bulk density, and porosity) of cocoa pod were measured by standards methods (Mohsenin, 1970; Pandiselvam et al., 2019b), observed in table 1,the mechanical properties were performed using Universal Testing Machine (UTM) to find out the rupture force at the bio-yield point in horizontal- and vertical-predilections (ASAE, 1998; Chamsing et al., 2006), coefficient of friction was determined with stainless steel (SS), aluminum (AS), galvanized iron (GI), and plywood sheet (PW) and the angle of repose was determined by a method of Mohsenin (1970)

Table 1
The dimensions of different designed components of coco beans extractor.

Sr.No	Components	Designed dimensions
1	Hopper	400 × 400 × 400mm
2	Metallic rollers	30 cm length × 8cm diameter
	Four sets of rollers with same size	
3	Gap between first and second rollers	80–100mm
4	Gap between second and third & third and fourth rollers	60–80mm
5	Length of Discharge Chute	200m
	Deep of Discharge Chute	45mm
6	Rotating cylindrical drum strainer	
	It consists of two concentrical or coaxial rotating inclined cylinder mesh made of wire screen mesh	
	1. Size of inner square mesh	2.5cm
	2. Size outer square mesh	3.75cm
	3. Diameter of inner cylinder	39cm
	4. Diameter of outer cylinder	43cm
	5. Length of inner cylinder	100cm
	6. Length of outer cylinder	100cm
7	Electric motor	0.25hp

2.3. Development of cocoa bean extractor

The main components of continuous cocoa beans extractor are feed hopper, discharge chute, rollers, cylindrical drum strainer, and prime mover as shown in Fig. 1. and Fig. 2. The frame was fabricated using GI sheet (3 mm thickness) and the feeding unit, roller, chute, and motor were mounted on the frame. The feed hopper has rectangular shape (400 × 400 × 400 mm) and made up of two mm thick low carbon steel. Discharge channel consisting of 2 mm low carbon steel with 40° inclinations towards horizontal to facilitate natural discharge. The chute was fixed at the bottom end of the roller assembly with 200 mm length and 45 mm rooted. Rollers are first functioning part of the equipment. It consists of four sets of calendar rollers of dimension 30 cm length and 8 cm diameter, of which two rollers were fixed while others were adjustable. The gap between the first and second rollers was varied between 80 and 100 mm. Similarly, the differences between second and third and third and fourth rollers were 60–80 mm and below 60 mm, respectively. The clearance between the rollers was adjustable based on the size of the cocoa pod. The roller has rough surface consist of tubes on a driller hole evenly separated along with the pipes. Its differential movement produces the impact and compression force against cocoa pods throughout pod breaking. Cylindrical drum strainer was used to separate the bean from a broken pod. It consists of two concentrical or coaxial rotating inclined cylinder mesh made of 2.5 cm inner size and 3.75 cm outer size wire screen mesh. The diameter and length of the inner cylinder was 39 × 100 cm and the outer cylinder was 43 × 100 cm, respectively. The inclination of strainer used in the range of 40 to 50°. An electric motor of 0.25hp having a speed of 1420 rpm was used as a prime mover for operation.

2.4. Design analysis of cocoa bean extractor

The design study and summations of cocoa bean extractor components have conducted in sequence to decide and choose the constituents of adequate strength and dimensions. Components of the bean extractor have been developed for the utmost breaking strength and tangential force (Kate et al., 2018; Pandiselvam et al., 2020) of the cocoa pod, which is 834 N.

Design of hopper

The hopper was designed to hold 10 kg of the cocoa pod at a time and developed based on the cocoa pod density. The hopper's volume was designed by viewing the safety and lending 20% of the calculated volume of cocoa to be fed at a time (Gana et al., 2017)

Design of Roller

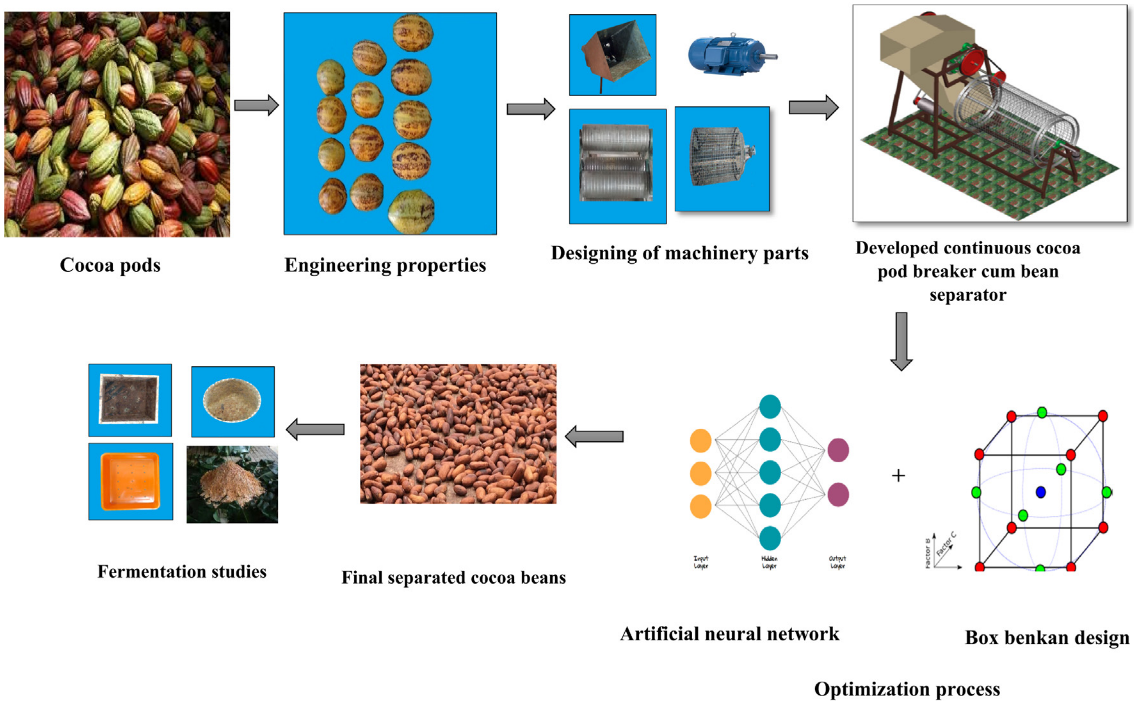

Fig. 1. Schematic flow chart for mode of operation machine.

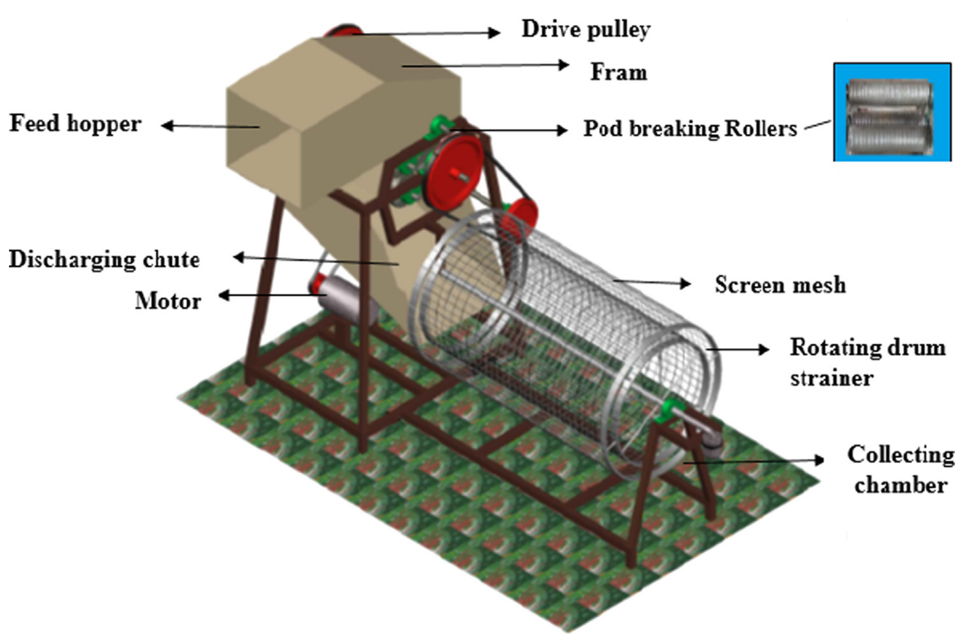

Fig. 2. Schematic view of continuous cocoa beans extractor.

The design of the roller depends upon the expected torque towards to outer shell of the cocoa pod and cocoa pod size. The roller dimension depends upon length and diameter obtained by following equations (Ibrahim et al., 2016)

$$V = \frac{\pi d^2}{4} L \quad (1)$$

$$d = \sqrt{\frac{4V}{\pi L}} \quad (2)$$

$$L = \frac{4V}{\pi d^2} \quad (3)$$

where d = diameter of roller

L = length of roller.

Thickness of rollers

$$\sigma = \frac{pd}{2t} \quad (4)$$

$$t = \frac{pd}{2\sigma} \quad (5)$$

t = thickness of the roll

σ = tensile strength of the roll

p = pressure

Torque towards to shaft

$$P = T.\, \omega \quad (6)$$

$$T = \frac{p}{\omega}$$

P = Power required, T = Torque on the shaft and w = Angular speed of the shaft.

Speed of Roller

The speeds of two rollers were fixed, while others two adjustable. First and third rollers are adjustable while the second and fourth rollers are fixed. It's interrelated with top and bottom rollers. It is calculated based on the following equation

$$N_L C_L = N_T C_T \quad (7)$$

$$N_T = N_L C_{L/} C_T \text{ for first roller} \quad (8)$$

$$N_L = 2(N_T T C_T)/C_L \text{ for third roller} \quad (9)$$

NL = speed of the bottom roller

N_T = speed of the top layer

C_L = corrugations on the bottom roller

C_T = Corrugations on the top layer

Clearance between two rollers

It depends on the size of the cocoa pod, roller diameter, and corrugated roller's pitch length. The rough space between first, and third rollers is adjustable while the second and fourth rollers are fixed and the formula of Okoye et al., (2008) and Ibrahim et al., (2016) calculated the clearance.

$$\text{Clearance between roller} = \frac{D_1 + D_2}{2p} \quad (10)$$

D_1 = Major diameter of the roller

D_2 = Minor diameter of roller

P = pitch length (approximately 10 mm)

Design of Extracting Strainer

The design of the strainer reckons on its inclined position, speed of rotation, and shaft length. The respective parts of strainer like diameter, length, size of the inner and outer cylinder were designed by following equations.

$$W = \rho V g = m \quad (11)$$

$$V = \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right)1 + 2\left(\frac{\pi d^2}{4}\right)t \quad (12)$$

$$m = \rho(\left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right)1 + 2\left(\frac{\pi d^2}{4}\right)t) \quad (13)$$

$$W = \rho(\left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right)1 + 2\left(\frac{\pi d^2}{4}\right)t)g \quad (14)$$

Finding of work done on breaking of cocoa pod

The work force required for breaking cocoa pod has been estimated as the area of a bounded region of force versus deformation curve (Koyuncu et al., 2004; Pandiselvam et al., 2020).

The breaking force was calcuted by using the following equation (Koyuncu et al., 2004; Kate et al., 2018).

$$F = (103{:}\ 5x - -100{:}\ 2) \quad (15)$$

$$W = \int_0^4 (103.5x - 100.2)dx \quad (16)$$

where, F is s function of breaking force (N); x is a function of deformation (mm); and W is function of work done (J).

Power consumption of equipment

The power needed to operate equipment has been estimated according to the method described by Gbabo (2002), Ghafari et al., (2011) and Kate et al. (2018).

Summery of design calculation

The summery of design calculation is shown in Table 1.

Cost economics of fabricated machine

It includes material cost, fabrication cost, fixed cost, variable cost and a payback period of the constructed machine is highlighted in Table 7.

Performance test

Cocoa fruit was fed manually into the breaker unit through feed hopper. A tangential force of the roller pushed the cocoa pod towards the gap resulted in breakage. Cocoa pod, kernels, and placenta were then discharged to strainer through a chute. Rotation ofstrainer has been separated the cocoa kernels from cocoa pod and placenta and passed through the mesh of the strainer.. The operation of the equipment was accessed by capacity, shelling efficiency, bean separation efficiency, beans damage percentage, energy requirement, and machine efficiency (Adewumi and Fatusin, 2006; Pradhan et al., 2010; Sharma et al., 2013; Kate et al., 2018).

3. Experimental design

The performance evaluation and experimental optimization from a designed prototype machine (Fig. 1) have been executed through the Box-behnken design (BBD) and artificial neural network (ANN).

3.1. Experimental design for box-behnken modelling

The design parameters (speed of the roller, and inclination angle of strainer) and cocoa pod properties, which influence machine capacity, efficiency, energy requirement, cocoa beans separation efficiency, shelling efficiency, and beans damage percentage of cocoa beans extractor were analyzed via Box-behnken design. The experimental compounding matrix of independent and dependent variables with 17 runs is shown in Table 2. In RSM, the most generally used second-order polynomial equation produced to fit the experimental data and assort the applicable model terms is showed in Eq. (17)

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1 X_3 + b_{23}X_2X_3 \quad (17)$$

Since Y is a function of predicted response, $b_{0,}$ $b_{1,}$ $b_{2,}$ and b_3 are linear terms, $b_{11,}$ $b_{22,}$ and b_{33} represent square terms, $b_{12,}$ b_{13} and b_{23} are interaction terms, X_1, X_2, and X_3 are the inscribed values of machine development. The statistical analysis and ANOVA have been reported by using Design Expert Version 9.0 a (Stat-Ease, Inc. USA)to find out the significance at 0.01%, 1%, and 5% for the linear, interaction, and quadratic of responses.

3.2. Artificial neural network (ANN) for prediction of machine performance

The ANN have an excessive prediction potentiality. Hence, a multilayer feed-forward neural network structure was developed to train a model for predicting the machine performance in terms of capacity, efficiency, energy requirement, cocoa beans separation efficiency, and shelling efficiency. The network of the developed ANN model concurred as three neurons in the input layer (the speed of the rollers (rpm), size of the cocoa pod (mm) and inclination angle of strainer (degree)); four neurons in the hidden layer; and five neurons in the output layer. The back-propagation algorithm been used to change coefficients and predetermines to get the lowest asses as a mean square error between the objective and the network yield through distributing an incline string algorithm (Nourbakhsh et al., 2014). The outline of the ANN model is depicted in Fig. 3. Whole computing was made with MATLAB R2018a programming. In the present study, the nonlinear tangent-sigmoid transfer (tansig) function were chosen with regards to activation of neurons in the hidden layer and linear transfer (purelin) functions for neuron activation at the output layer. The network topography of the generated ANN model has been allotted as 3-9-1. The comparable experimental data arranged for BBD has been used in

Table 2
Machine development experimental (Box–Behnken) design and its performance parameters.

Run	Independent Variables			Dependent Variables					
	Speed of the rollers (rpm) (A)	Size of cocoa pod (mm) (B)	Inclination angle of strainer (degree) (C)	Capacity (kg/h) (Y_1)	Efficiency of machine (%) (Y_2)	Energy requirement (kJ) (Y_3)	Cocoa beans separation efficiency (%) (Y_4)	Shelling efficiency (%) (Y_5)	Beans damage Percentage (%)
1	260	160	50	553.56	94.53	12.12	84.2	94.3	< 1
2	360	160	45	579.71	95.43	11.58	86.5	96.31	< 1
3	360	140	40	610.67	95.63	11.15	83.5	94.3	< 1
4	360	160	45	579.71	95.43	11.58	86.5	96.32	< 1
5	460	160	50	610.16	96.32	11.00	84.3	94.4	< 1
6	360	160	45	579.71	95.45	12.00	86.2	96.42	< 1
7	360	160	45	579.71	95.85	11.58	86.5	96.42	< 1
8	260	180	45	512.33	94.93	13.10	86.4	96.12	< 1
9	360	180	40	535.55	96.9	12.86	83.4	94.1	< 1
10	360	160	45	579.71	95.47	11.58	86.4	96.42	< 1
11	260	140	45	586.95	94.16	11.43	86.5	96.42	< 1
12	460	180	45	564.21	96.67	11.38	86.5	96.01	< 1
13	360	180	50	535.55	95.54	12.86	84.2	94.3	< 1
14	460	140	45	626.81	96.97	10.71	86.5	96.11	< 1
15	360	140	50	610.67	95.3	12.90	84.5	94.4	< 1
16	460	160	40	610.16	96.67	11.00	83.2	94.2	< 1
17	260	160	40	553.56	94.53	11.43	83.3	94.5	< 1

favour of simulation through the ANN technique. Various kinds of network topography been trained, tested, and subsequently validated by adjusting the quantity of neurons in the hidden layer over the range of 1–15 by decreasing deviations among the empirical and predicted values. During training progress, a whole experimental data (17runs) was replicated thrice (51 entries), split into three segments:70:15:15 (%) for training, validation, and testing (Sudha et al., 2016).

4. Results and discussion

4.1. Engineering properties of cocoa pod

The engineering properties of cocoa pods could be useful for development of pod breaking machine. The physical properties of cocoa pod such as lenth (124–188 mm), diameter (73–97 mm), sphericity (0.62–0.70), volume (293–785 cm^3), bulk density (384–417 kg/m^3) and porosity (47–55%), were used to design the hopper. The frictional properties (SS-0.29 to 0.33, AS-0.32 to 0.34, GI-0.34 to 0.40 and PW-0.33 to 0.39) on different materials would be useful for fabrication material selection and designing of various components including chute. The angle of repose deviates within 20.07° to 25.17° . Thereby the stainer angle was kept more than 40° as convenient for flow of beans and shell.

4.2. Interpretation of Box-Behnken design (BBD) model

The experimental results are expressed in Table 2. Multiple linear regression models were developed and utilized to translate the impact of several independent variables upon responses. The model's adequacy was assessed by considering the coefficient of determination (R^2), Fisher F-test, and Lack of fit (Table 3). It also shows that significant parameters influence each model in predicting their corresponding responses (Table 4)

4.3. Bean extractor capacity

The experimental data are shown in Table 2. The bean extractor capacity ranged from 512.33 to 626.81 kg/h. The bean extractor's maximum capacity was observed at 460 rpm roller speed and 140 mm cocoa pod size combination.. Whereas, the lowest values were found to be 260 rpm and 180 mm, respectively. The capacity depends upon roller speed and pod size (Widyoto et al., 2009). The coefficient of determination (R^2 = 99.5) for the regression model of capacity was extremely significant (< 0.0001), and lack of fit was to be non-significant. The effect of roller speed and cocoa pod size on the machine's capacity is shown in the 3D (Fig. 4a). The capacity is continuously increased by increasing roller speed (260–460 rpm), whereas by increasing pod size (140 to 150 mm) initially increased and then steadily decreased. The continuous increase of capacity with roller speed due to an increase in shear rate and pressure between rollers causes rubbing action that leads loosening of husk and easy removal of the pulp. In the beginning, capacity increased later decreased because of smaller fruits fitted the spacing between the rollers more accurately induce quick breaking further reduced due to less allocate space and more weight of the product (Widyoto et al., 2009).

4.4. Breaking efficiency of pod breaker

Breaking efficiency is a critical parameter for machine capacity. The observed value for breaking efficiency varied between 94.16 and 96.9% (Table 2). Statistical regression depicts that the breaking efficiency had significantly ($p < 0.001$) affected by the speed of the roller and size of the cocoa pod at a linear level and quadratic level (Table 3). The numerical equations developed in the variance of the breaking efficiency

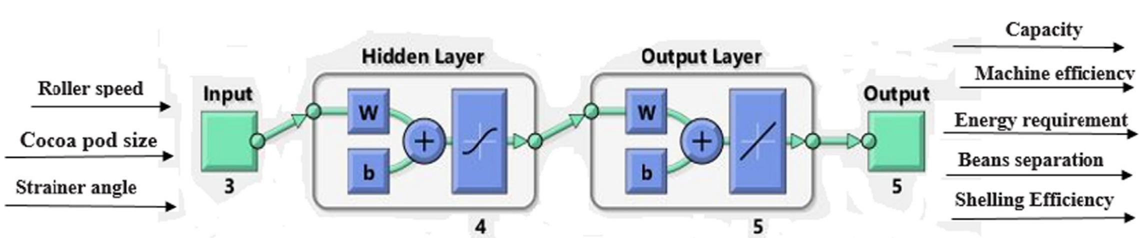

Fig. 3. Configuration of multilayer ANN model with three input neurons, four hidden neurons and five output neurons.

Table 3
F-value, P-value and significance of each variable on performance parameters of coco beans extractor.

source	Capacity		Efficiency		Energy requirement		Cocoa beans separation efficiency		Shelling efficiency	
	F-Value	P-value	F-Value	P-value	F-Value	P-value	F-Value	P-value	F-Value	P-value
Model	156.87	< 0.0001	408.94	< 0.0001	14.92	0.0009	281.74	< 0.0001	15.67	0.0008
A	466.6326	< 0.0001	10.56708	0.0140	31.8988	0.0008	0.10233	0.7584	116.5172	< 0.0001
B	918.0715	< 0.0001	13.47	0.0080	32.2194	0.0008	2.5584	0.1537	6.35226	0.0398
C	0	1.0000	2.474081	0.1597	11.9291	0.0106	147.7778	< 0.0001	6.7430	0.0356
A^2	0.244024	0.6364	4.408552	0.0739	19.1020	0.0033	0.7777	0.4071	0.4107	0.5420
B^2	23.60818	0.0018	19.20095	0.0032	18.4611	0.0036	3.6217	0.0988	3.2294	0.1154
C^2	0.674492	0.4386	3553.585	< 0.0001	4.40593	0.0740	2370.824	< 0.0001	0.2928	0.6052
AB	3.210411	0.1163	2.199183	0.1816	4.00737	0.0854	0.20467	0.6647	3.7101	0.0955
AC	0	1.0000	8.796733	0.0209	1.90791	0.2097	0.81871	0.3956	0.3969	0.5487
BC	0	1.0000	0.549796	0.4825	12.2725	0.0099	0.81871	0.3956	3.4379	0.1061
R^2	0.991		0.994		0.950		0.990		0.950	
Adjusted R^2	0.9887		0.9956		0.8867		0.9937		0.8919	
Predicted R^2	0.9210		0.9810		0.4386		0.9875		0.4107	
SSE	15885.37		10.88		8.38		30.97215		16.74	
LOF	NS		NS		NS		NS		NS	

Table 4
Quadratic models developed using independent variables from machine development experimental design.

Properties	Model
Capacity	$Y_1 = +579.71 + 25.62A\text{-}35.93B\text{-}7.94B^2$
Efficiency of machine	$Y_2 = +95.53 + 1.06A + 0.25B\text{-}0.087\ A^2 + 0.24B^2 + 0.073C^2 - 0.088A \times C$
Energy requirement	$Y_3 = +11.66\text{–}0.50A + 0.50B + 0.31C\text{-}0.53A^2 + 0.52B^2 + 0.26C^2\text{-}0.25AB\text{-}0.44BC$
Cocoa beans separation efficiency	$Y_4 = +86.42 + 0.013\ A + 0.10B^2\text{-}2.62C^2$
Shelling efficiency	$Y_5 = +96.38\text{–}0.077\ A\text{-}0.087B + 0.038C + 0.050AB$

with different variables (A, B, C) were well fitted in the second-order multinomial equation (Eq. (3)). The high $R^2 = 0.99$ (Table 3) value indicating the familiarity between observational and predicted values, thereby suitability of the model. The 3D surface plots show utilitarian perceptivities on finding the effect of machine development on breaking efficiency (Fig. 4b). The cocoa bean extractor's breaking efficiency increased significantly with an increase in roller speed and cocoa pod size. Highest breaking efficiency was found at a roller speed of 460 rpm for large size cocoa pods (180 mm). Similarly, the minimum breaking efficiency recorded at 260 rpm for small size cocoa pods (140 mm). This may be due to more impact of the roller on the shell of the cocoa pod, and also high compression pressure generated between rollers and its outer casing during the high speed leads to maximum breaking efficiency. In contrast, the reverse trend observed during minimum breaking efficiency at low rate of roller due to less compression and low impact between rollers and its outer casing (Aliu and Ebunilo, 2012). Pradhan et al., (2010) reported the same information that an enlarge of the cocoa pod size initially increased breaking efficiency after that constant due to more robust influence of compression force above on impact force, which would humiliate the pod subsequently breaking the outer shell.

4.5. Energy requirement of cocoa bean extractor

The values of the energy requirement of the cocoa bean extractor ranging from 10.71 kJ to13.10 kJ (Table 2). The maximum energy requirement of the cocoa bean extractor was showed at 260 rpm roller speed and 180 mm size of the cocoa pod. In contrast, the minimum energy requirement for breaking the cocoa pod was observed at 460 ± 10 rpm roller speed and 140 mm size. A simplified equation (Eq. (4)) was formulated based on second-order polynomial, which reports only the effect of significant work on variables on energy requirement. The coefficient of determination (R^2) for the regression equations (energy requirement) around 95%, the model was extremely significant ($p < 0.0001$), and lack of fit were to be non-significant ($p < 0.05$) which suggests that the model was fitted between date based and anticipated values. The energy requirement of the machine was initially decreased and subsequently increased with pod size, while the reverse trend observed with roller speed, declined in a convex shape (Fig. 4c). Adewumi and Fatusin (2006) also found a similar effect on hand-operated cocoa bean extractor. This may be due to energy requirement had an inverse relationship with roller speed and a direct relationship with cocoa pod size and also increase in screw speed increases shear rate, which reduced energy requirement. Another reason the eject of a large number of cocoa pods from the rollers by the unit time on significant raise in magnitude from whole forces pretending on the pod when passing from the first roller to the fourth roller leads more energy consumption by increasing the size (Vishwakarma et al., 2016).

4.6. Beans separation efficiency

The value for cocoa beans separation efficiency varied from 83.2 to 86.5% (Table 2). The maximum beans separation efficiency was obtained at 45° inclination. Table 4 shows the quadratic model fitted to the beans separation efficiency data found at respective experimental conditions. The R^2 of 0.9972 and adjusted R^2 of 0.9937 values showing the best fit for the given data for beans separation efficiency. Liu et al. (2010) indicated that the higher the value of adjusted R^2 being nearer to 1, the greater the degree of correlation between the experimental and anticipated value. This successively shows the suitableness of the given model. To ascertain the best fit of the selected model, the normal plot of residuals was taken from the design expert software. Fig. 4d depicts that the beans separation efficiency of strainer increased (82–86.5%) with an increase in strainer orientation (inclination angle of strainer 400–450°) after that suddenly decreased. It is t showing in a concave manner since the efficiency of strainer slantly increased with roller speed, as a consequence of more inclined of strainer holes by enhancing strainer angle that creates access to separate beans from the placenta (Okoye et al., 2008). The maximum beans separation efficiency was obtained at 45° inclinations. Also, beans separation efficiency increased by rising the speed of strainer rotation as a result of strengthening in centrifugal force, which causes to twirl those beans with the mesh of

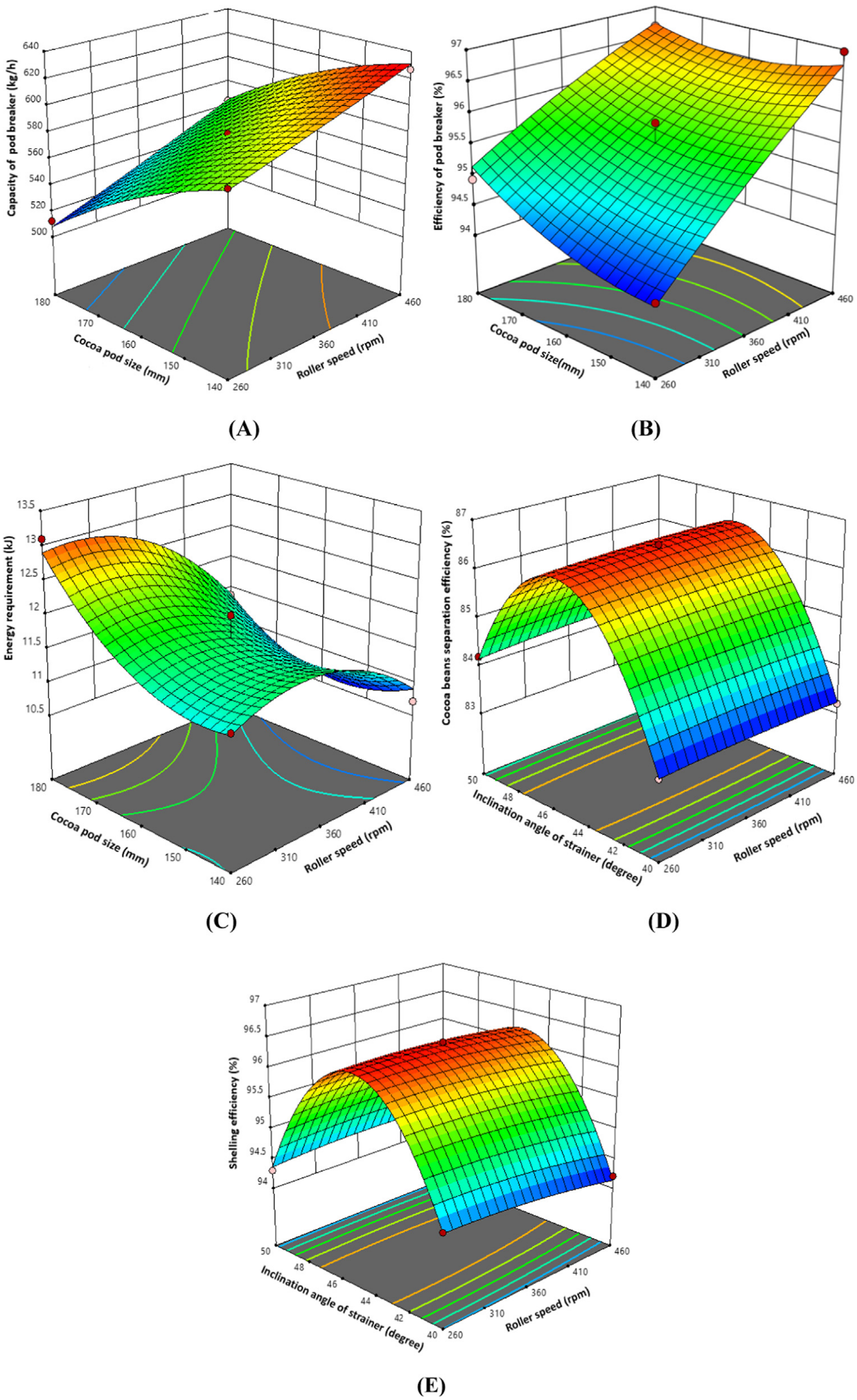

Fig. 4. Response 3D exemplifying the consequences of roller speed, cocoa pod size and inclination angle on (a) Capacity, (b) Efficiency of pod breaker, (c) Energy requirement, (d) cocoa beans separation efficiency and (e) shelling efficiency of cocoa beans extractor.

sieve through a higher impulse that provides to the maximum separation of beans from cocoa pod shells (Sharma et al., 2013).

4.7. Shelling efficiency

Shelling efficiency of cocoa bean extractor ranging from 94.1% to 96.43% throughout total observational conditions (Table 2). The maximum shelling efficiency was incurred at 45° inclinations. A multinomial quadratic equation was accommodated to the shelling efficiency observational data, which develops a regression model depicted in Table 4 (Eq. (5)). Greater R^2 (0.952), adjusted R^2 (0.891), and lack of fit non-significant indicated that the suitability model represents familiarity between the database and prognosticated values.. The shelling efficiency at the early stage increased by increasing the inclination angle of strainer further decreased, its exhibits like parabolic shape with inclination angle, similarly the shelling effciancy slightly increased with roller speed (Fig. 4e). This may be due to more impact of strainer upon cocoa pod shell, which ensures for their splitting and detachments from the cocoa pod. But later, the shelling efficiency was decreased due to high inclination and speed of strainer, the seed coats were slippery. They rolled down along with the beans by without separation leading over eminent strength of friction required to detach pod shells from beans (Pradhan et al., 2010).

4.8. Bean damage percentage

For developed cocoa been machine, low values (< 1) for beans damage percentage are desirable in all the experiments. Machine capacity and pods shelling efficiency increased while the bean's damage percentage decreased and had no effect on the strainer's inclination.

Model accesses

The results of Box-Behnken design (BBD) models created utilizing polynomial response equation (Eq. (17)). Genrally significant parameters have been utilized to formulate the multiple linear regression equation for anticipating corresponding parameters. The models were created using mearly the critical parameters of Table 3 been redesign through MATLAB's "fitlm" operations were displayed in Table 4. This may be detected that the linear equations being compress about only the significantly affecting responses, and the performances have been enhanced. Consequently, the current regression models (Table 5) been approved as predicting the machine design parameters rather than the models shown in Table 4.

Interpretation of artificial neural network (ANN)

The ANN model was also formulated to compare the performance with the BBD model. The ranges of ascertained and predicted evaluation were nearly in a similar range (0.99–1) (Table 5 and Table 6). The correlation between experimental and predicted values are shown in Fig. 5. Contrasting the earlier research (Sanaeifar et al., 2018) consisting of five neurons in the output layer and four neurons to be optimized in the hidden layer was ample to develop excellent performance in the current research. The performance of entire ANN models was superior over the BBD models conferred in Table 5. The ANN models' R^2 values ranged from 0.94 to 0.99, and mean square error (MSE) values ranged from 0.0017 to 0.0074. Both (ANN and BBD) models were desirable for predicting the capacity and reported maximum R^2 values of 0.999 and 0.991. The higher R^2 and the minimum MSE values of ANN

Table 6
Performance measure of artificial neural network model.

Variables	Experimental range	Predicated range	R^2	MSE
Capacity (kg/h)	512.3–626.8	512.3–612	0.999	0.0074
Efficiency of machine (%)	94.1–96.6	94.2–96.9	0.94	0.0031
Energy requirement (kJ)	10.71–13.1	10.8–13.0	0.96	0.0029
Cocoa beans separation Efficiency (kJ)	83.2–86.5	83.3–86.6	0.98	0.0013
Shelling efficiency (%)	94.1–96.32	94.2–96.3	0.98	0.0017

Table 7
Cost economic of cocoa pod breaker.

Annual cost Developed continuous cocoa pod breaker		
1.	Capacity of cocoa pod breaker	550.5kg/h
2	Total cost of equipment (Annual usage-120 days, Daily usage-6 h, Interest rate-10.5% per annum,)	Rs. 27,600/-
3	Fixed cost (Fixed cost of equipment + Housing charge)	3134.10 INR per year (Rs. 1934.10/- +1200)
4	Variable costa) Repair and maintenance (5% of initial investment)b) Labour cost,	1380 INR per year 48,000 INR per year
5	Miscellaneous Power consumption	1072.8 INR per year
6	Total annual cost (3 + 4 + 5)	53,586.6 INR per year
7	Cost of raw material Raw cocoa pods	25 INR per kg
8	Operating cost of machine per hour Beans obtained from 100 kg of cocoa pod	Rs. 74.42/- 30.50kg
9	Gross Annual benefit (Total Cost of obtained beans per year) (7 × 8)	16,647,120 INR per year
10	Annual net benefit (9–6)	16,593,538 INR per year
11	B/C ratio	1.67:1
12	Payback period	2.01 year

Table 5
ANN design (experimental and predicted values) for performance of cocoa beans extractor.

Capacity (kg/h) (Y_1)		Efficiency of machine (%) (Y_2)		Energy requirement (kJ) (Y_3)		Cocoa beans separation efficiency (%) (Y_4)		Shelling efficiency (%) (Y_5)	
Exp.	Predicted	Exp.	Predicted	Exp.	Predicted	Exp.	Predicted	Exp.	Predicted
553.56	553.55	94.53	94.57	12.12	12.04	84.2	84.10	94.3	94.40
512.33	512.32	94.93	94.96	13.1	13.00	86.4	86.33	96.12	96.19
586.95	583.17	94.16	94.25	11.43	11.44	86.5	85.96	96.42	96.11
553.56	553.56	94.53	94.41	11.43	11.45	83.3	83.36	94.5	94.44
579.71	579.70	95.43	95.55	11.58	11.63	86.5	86.43	96.31	96.35
610.67	610.66	95.63	95.74	11.15	11.10	83.5	83.44	94.30	94.34
579.71	579.70	95.43	95.55	11.58	11.63	86.5	86.43	96.32	96.35
579.71	579.70	95.45	95.55	12.00	11.63	86.2	86.43	96.42	96.35
579.71	579.70	95.85	95.55	11.58	11.63	86.5	86.43	96.42	96.35
535.55	533.94	96.9	96.75	12.86	12.47	83.4	83.67	94.10	94.45
579.71	579.70	95.47	95.55	11.58	11.63	86.4	86.43	96.42	96.35
535.55	535.54	95.54	95.53	12.86	12.76	84.2	84.24	94.30	94.23
610.67	612.04	95.3	95.22	12.9	12.82	84.5	84.43	94.40	94.44
610.16	610.16	96.32	96.27	11.00	11.18	84.3	84.35	94.40	94.35
564.21	559.21	96.67	96.55	11.38	11.44	86.5	86.68	96.01	96.22
626.81	626.81	96.97	96.92	10.71	10.89	86.5	86.43	96.11	96.19
610.16	611.64	96.67	95.99	11.00	10.84	83.2	83.53	94.20	94.35

Exp. = Experimental.

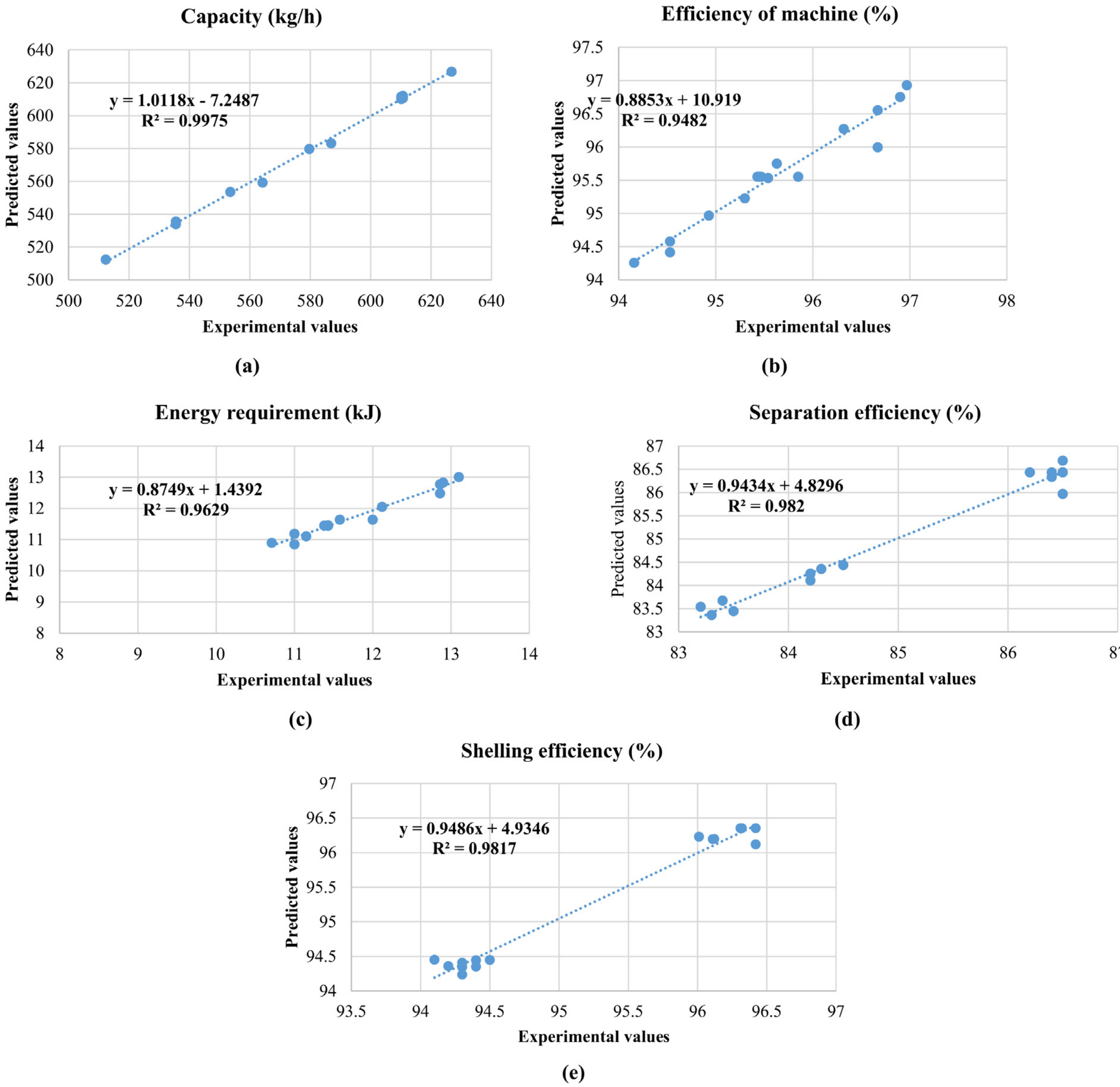

Fig. 5. The relationship between experimental values and predicted values for the models developed using artificial neural network. (a) Capacity, (b) Efficiency of pod breaker, (c) Energy requirement, (d) cocoa beans separation efficiency and (e) shelling efficiency of continuous cocoa beans extractor.

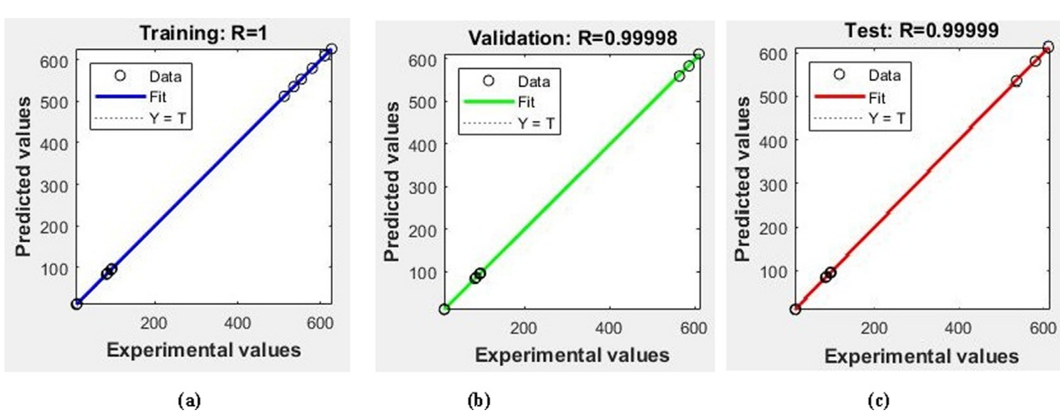

Fig. 6. Regression plots for the training (a) validation (b) and (c) Test for cocoa beans extractor ANN model.

while evaluating of better accuracy and reliability (Saldaña-Robles et al., 2020). Simultaneously, both models yielded minimum R^2 in predicting the energy requirement of the machine (0.95 and 0.96), it demonstrates that the model might is suitable for predicting energy requirement. Rests of the other models have been satisfactory. Despite that, the ANN models might be enhanced by utilizing more significant hidden neurons since every single model, yet there are possibilities of model overcrowding. Consequently, through a said decision on the number of neurons by Patrício and Rieder (2018), the created models are being implemented properly. The mean square error from the trained network exists $1.39928e^{-2}$, along with a regression coefficient of around 0.99. The schemes from that trained network and the regression schemes about training, validation, and test are shown in Fig. 6, respectively. Comparing ANN and BBD, the performance of ANN was superior; therefore, it may be utilized to predict machine design and performance parameters for future research.

Optimization of predicted variables

Multi response optimization for the controlled variables was conducted by applying Design Expert 8.0.5. To optimize the machine operational parameters, the goal were stetted to maximize machine capacity, efficiency, strainer beans separation efficiency, shelling efficiency, and minimum machine energy and beans damage percentage.

The desirable (0.98) optimum variable for cocoa beans extractor is the speed of roller of 360 rpm, size of cocoa pod of 160 mm and the inclination angle of strainer of 45°. The cocoa beans extractor outcome under this optimum condition of actual values (626.8 kg/h, 96.78%, 10.54 kJ, 84.8 kJ and 95.17%) and predicted values (579.7 kg/h, 95.5%, 11.66 kJ, 86.4 kJ and 96.3%) for capacity, the efficiency of pod breaker, energy requirement, cocoa beans separation efficiency and shelling efficiency, respectively. Therefore the picked out models are accurate to constitute variations in all the responses.

Cost economics of continuous cocoa bean extractor

The cost economics for a developed continuous cocoa bean extractor was calculated and depicted in Table 7. The operating expenses of an improved cocoa bean extractor showed that 74.42INR per hour is lower than the manual method (Rs. 150per hour). The designed continuous cocoa bean extractor capacity showed that 626.8 kg per hour in the most favorable condition. The time needed to break and separate kernels from 100 kg of cocoa pods was 7.01 min, it's less than the manual method (50 min) observed in Table 7 (Widyoto et al., 2009; Kate et al., 2018). The compensation period for the evolved precursor model of continuous cocoa bean extractor was 2.01 years; at the same time, B:C proportion was 1:67:1.

5. Conclusion

The present study concentrated on the design and development of continuous cocoa bean extractor. During design, the outcome from the operation valuation disclosed that the shape of the pod, roller speed, and inclination of the strainer of the machine had more impact on machine performance pursed by roller clearance. BBD and ANN model have been applied for modeling and optimizing machine performance conditions. BBD and ANN regression coefficients have been found to maximum 0.994 and 0.999, accordingly signifying outstanding compliance with the experimental data. These two techniques confirmed to be beneficial tools regarding the optimization of designed machine performance. The maximum value of the correlation coefficient and minimum values of mean square error for ANN represents better prediction for experimental data over BBD. The developed cocoa bean extractor operation cost, the total cost of the machine, and the payback period were Rs.74.42/h, 27,600/- and 2.01, respectively, it would be lesser than the expensive manual method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The financial support received from the Department of Food and Agricultural Process Engineering, Kerala Agricultural University, is gratefully acknowledged.

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