Development and Evaluation of Palmyrah (*Borassus Flabellifer* L.) Fruit Pulp Extractor

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Abstract: Palmyrah (*Borassus flabellifer* L) fruit pulp is available abundantly and has a high potential for food in rural areas, useful for pharmaceutical and cosmetic applications, however, the main hindrance for this pulp is lack of mechanization and availability of pulp in sufficient quantity at one place. The pulp of this fruit is usually used by rural communities where the processors use manual pulping, which is not only time-consuming but yields seasonally during July and August in India. Therefore, the objective of this work was to design, develop and evaluate the efficiency of fruit pulp extractors. The pulper was designed and developed such way that to be compact and easy to operate, consisting of the main housing with stainless steel teeth on a rotating shaft and pulping performed by beating and shearing. The performance evaluation of the machine was carried out at different rpm (320, 360, 410) input capacity (8, 10 and 12 kg) for fixed time of operation is 6 minutes. The pulp weight was evaluated during the pulping process period. The highest pulping efficiency (84.78%) and pulp recovery (33.9%) was obtained rpm of 410, with 6 minutes of pulping, and batch capacity of 10 kg of fruits which resulted in a capacity of 50 kg fruits per hour. This high efficiency makes this mechanized effective for pulping palmyrah fruits and, thus, it can replace manual pulping, especially in rural communities involved with the palmyrah fruit pulping.

Keywords: Palmyrah fruit pulp, Natural foods, Mechanization

Citation: Vengaiah, P. C., S. Kaleemullah, M. Madhava and T.A. D. Srikanth. 2023. Development and Evaluation of Palmyrah (Borassus Flabellifer L.) Fruit Pulp Extractor. Agricultural Engineering International: CIGR Journal, 25(4): 186-195.

1 Introduction

Native wild fruits of India are a source of income for many families in rural areas, contribute to biodiversity conservation and are related to cultural richness. Utilisation of fruits is very scarce due to mechanization solutions are not developed. Specific devices for fruit processing, related to cottage level extraction for small farmer are very scarce and requirement demand is high.. Palmyrah (*Borassus Flabellifer* L) is one of the most abundant native fruits of Asia, especially in the States of south India. The edible yellowish red coloured and mild sweet pulp is fibrous, mucilaginous, and strongly adhered to the rigid fibre and dark endocarp, hindering the pulping process. Palmyrah pulp has high nutritional value due to its high contents of carbohydrates, proteins, carotenoids, and fibers, which are important for human health ((Sankaralingam et al., 1999; Vengaiah, et al., 2017).). Scientific studies showed the use of this pulp and seed to elaborate edible products, such as food bars, fruit beverage, snack foods, and bakery products, which are considered a source of fiber and vitamin A((Kurian et al., 2017).).

Received date: 2021-12-02 **Accepted date:** 2023-07-30

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This fruit can also be used to prepare ice creams, jellies, and cakes (Jansz et al., 2002). Palmyrah pulp is currently used by rural communities through artisanal procedures. Palmyrah pulp also has industrial potential for pharmaceuticals and cosmetics and for biofuel production, due to its fatty acid composition((Vengaiah et al., 2021a). The major drawbacks of these applications are the non-availability of pulp in bulk at one place, due to the slow process of manual pulping. Thus, the manual pulp production shall be progressively replaced by mechanized methods to increase the productivity and improve work conditions. Research aims to develop practical solutions for mechanization for extraction of pulp from palmyrah.

The mechanized device leads to the consolidation of the local rural activity and contributes to the decrement of social problems, and reduction of drudgery for rural exodus. Therefore, the unavailability of off-the-shelf compact devices promotes the opportunity to their development, looking for practicality and useful products obtained from resources from the biodiversity. Thus, therefore, the development of pulp extraction unit has been used for assessments on productive systems used by rural communities in line with other machineries developed pulper for Kendu (hashikumar et al., 2021a, 2017)) developed and optimised Sal (Shorea robusta) seed decorticator. Gbabo et al. (2013)) evaluated the mango juice and seed extractor. The use of shear extraction increases the efficiency of the process and preserves the nutritional characteristics of the fruits. It simulates the physical conditions of the pulp traditionally extracted and favors the homogeneity of the product. Mechanical extraction of pulp increases the efficiency of this process and favors the product standardization. Thus, this work intended to develop a technology specifically for rural communities, which need devices for pulp extraction of native fruits, help to increase the income of these communities and preserve the pulp of palmyrah Therefore, this study is intended to development of a palmyrah pulp extractor.

2 Material and methods

2.1 Material

Fresh fallen palmyrah fruits were procured from palmyrah field at HRS Pandirimamidi(17.25 North Latitude, 81.45 East longitude) and utilised for experiments. The fruits were cleaned, sorted and discarded the damaged ones. The good quality, undamaged fruits were divided into two samples from each type of fruit. The first samples were peeled and separated from the nut; while the second samples were without peeling. The proceed was optimised based on trial experiments, the fruits were dipped in hot water(50^o-60^{o}C) for 2 minutes and peeled manually and feed into the pulper in order to operate the pulp extractor to crush the fruit whose pulp is to be extracted.

2.2 Development of machine

The engineering properties of the fruits that are relevant to the design, development and performance evaluation were considered ((Vengaiah et al., 2021b). The properties include crushing strength, moisture content, size, true and bulk densities. Other factors considered were strength of machine components, cost of construction, ease of operation and maintenance and energy requirement. The extractor works on the principle of compression and shear, selection of materials and sizes of machine components.

2.2.1 Design of palmyrah fruit pulp extractor

Palmyrah pulper consists of hopper cum housing, beater assembly, power transmission and motor. They are designed to separate pulp of 15 kg of palmyrajh fruits per batch as follows.

Hopper cum housing and screen

Pulp extraction from fruits takes place by shear and impact force by beater in U shape trough. The trough bottom is with half cylindrical shape and top one with cuboid. The maximum capacity of the hopper cum housing was assumed to be 15 kg per batch. Bottom of the cylindrical part was used to keep fruits for pulp separation up to 15 cm from bottom and the remaining area of housing was left free for free movement of fruits for pulp separation in cylindrical portion and cuboid facilitate the moment of beater assembly and to avoid slippage of fruits from housing.

2.3 Machine Description and Operation

The pulp extractor was designed to work on the principle of shearing and squeezing due to the impact between conveyor housing and teeth. It is made up of five units, namely tool frame, feed section, pulp extraction unit, collecting unit, and power and transmission unit (Figure 1).

Figure 1 Palmyrah fruit pulp extractor with inside vide

The frame is made up of mild steel having an angle cross-section. The tool frame forms a rectangular shape in bottom and side along with of 1350 mm × 750 mm × 1200 mm. It supports and holds the machine parts and gives it overall compact outlook. The feed opener, which is mounted on top of the housing, is rectangular in shape and parallel to housing that enabled easy feed into the housing to be achieved. The feed opener has rectangular of 900 mm × 440 mm. It is made of stainless steel sheet of 1.6 mm thickness.

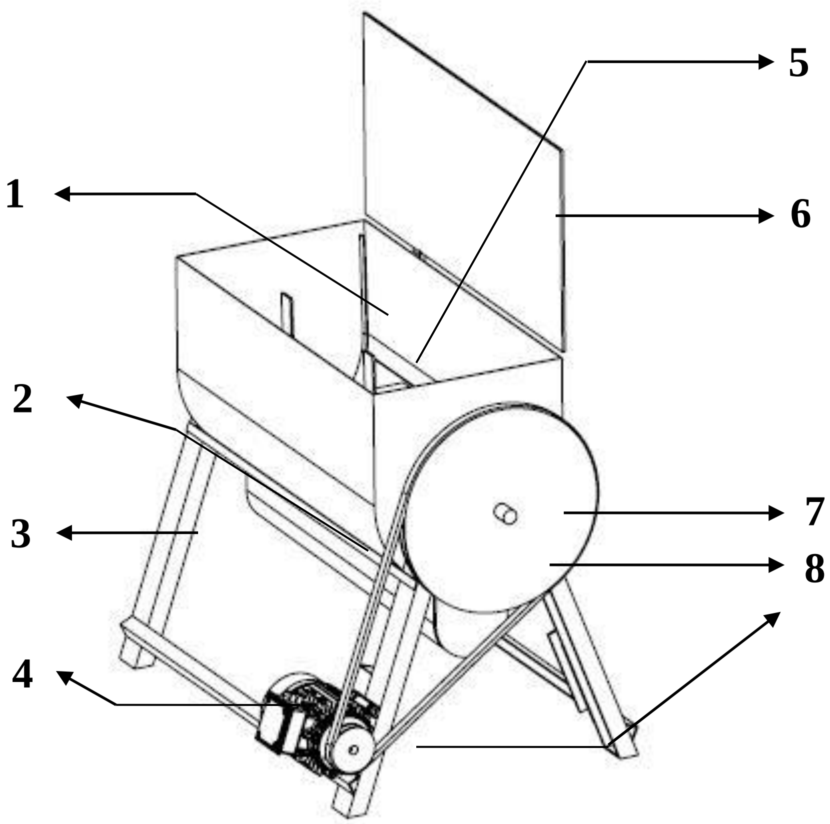
Hosing mounted on the tool frame, is the U shape pulp extraction unit that formed a housing of 440 mm diameter and 900 mm length, where pulp extraction takes place. Through this housing runs a shaft containing stainless teeth of 130 mm × 50 mm size along the Stainless steel shaft and rotate in the housing. The shaft and teeth assembly receives power via the belt and pulley and runs in a bearing. The teeth on the shaft are 77 mm apart on the shaft and angle between the teeth is 90^{o} along the shaft. The shaft and housing provide the shear and compressive forces needed to crush the fruit and squeeze out the pulp.

At the bottom of the housing, a separate sheet of a perforated concave screen made of stainless steel was attached. It permits the pulp extracted from the fruit to be filtered from the crushed fibre. The filtered pulp drops on pulp collection channel and flows down into the pulp collector.

The power unit consists of a 1 hp 1440 rpm electric motor, which powers the machine via a belt, pulleys and revere switch arrangement. The motor is mounted on a seating located at the base of the tool frame. The reverse switch is powered by a shaft on which a pulley is mounted and driven by a belt which receives power from a pulley mounted on the motor shaft. The orthographic view and part list of the pulp extractor are presented in Figure 2.

2.4 Operation of pulper

The motor was started by switching on the main switch and power is transmitted through the belt, pulleys to rotate the teeth arranged shaft. As the shaft rotates within the housing the teeth beaten the fruit from the wall of the housing and moves them through the extraction chamber toward the collection point. Based on the trial experiments time required for maximum extraction of pulp was six minutes for both direction each. During this movement, the fruit is crushed and pulp is squeezed out due to the shearing and compression in gap between the housing and teeth. The pulp extracted is passed through a screen and collected into a pulp collector, while the nuts and waste are channel through the bottom of housing.



1.Pulping chamber, 2.Discharge chute, 3 Frame, 4. Electric motor,
5. Beater, 6. Closing lid, 7.Pulley, 8. Shaft

Figure 2 View of the palmyrah fruit pulper

2.5 Bill of Engineering Measurement for Production

The cost of producing the extractor is presented in Table 1. This comprises the cost of components bought, cost of materials and parts fabricated and cost of machining and non-machining jobs.

Table 1 Bill of engineering measurement of a unit of juice extractor

S.No	Component	Material	Specifications	Cost (Rs.)
1	Main frame	Mild steel	Angle (2×2)	1600
2	Housing	Stainless steel (304)	2 mm (2m × 1m)	8000
3	Shaft	Stainless steel (304)	3mm(350 mm dia)	1600
4	MS Shaft	Mild steel	30 mm(175 mm leanth)	500
5	Screen	Stainless steel (304)	2 mm (0.6m × 0.8m)	800
6	Teeth	Stainless steel (304)	4 mm(130 × 60mm)	
			12 Nos	1800
7	Motor		1 hp single phase	8200
8	Drive mechanisam		V Belt B78	250
			Pully 100mm	400
			Pully 350mm	550
9	Bearing	Mild steel	Ball bearing	
			175 mm × 32 mm	
			2 nos	1600
10	Switch and wires		16 amps	300
11	Painting and labour charges			4400
	--- Total			30000

2.6 Mode of operation and testing

The pulper works as a beating cum pulping machine to extracts pulp from palmyrah fruit. The main shaft with the attached stainless-steel teeth squeezes the peeled fruit against the housing and perforated screen and presses out the pulp, leaving behind the fibre and nuts. The pulp is collected at the bottom, while the nuts and fibre are discharged along the horizontal axis of the main shaft.

The designed machine was fabricated and tested for its performance. Ripe and matured Palmyrah fruits were fed manually into the housing after hot water dipping for 2 minutes followed by peeling. Small quantity (250 ml) of water was added along with the fruit to facilitate easy flow. The quantity of water was fixed based on trial and error method so as to ensure easy flow of the material with minimum water. The performance of the pulper was evaluated, ranges of values for speed, and input capacity for batch of the machine were determined. Time of operation was kept constant and fixed as six minutes.

The feed weights (8,10, and 12 kg) and main shaft speed (320, 370 and 420 rpm). The parameters were optimized using central composite design (CCD) to obtain pulper parameters. The different weights of extraction for pulp, fibre, and nuts were recorded for calculations of various performance indices. The experiments were replicated, and the data were collected in triplicate.Table 2 Parameters used for Optimisation of pulper for performance

S.NO	Parameter	Value
1	Time of operation (Minutes)	6
2	Speed (rpm)	320, 370 and 410
3	Feed input, (kg) or number of fruits	8, 10 and 12

2.7 Performance Tests and Evaluation

The machine performance test was carried out by feeding a known mass of fruit into the pulp housing while running the machine. The power source was switch on to run the electric motor, which in turn powers the machine. The fruit were then delivered in to the extraction chamber and the machine was allowed to operate until the material was completely fed and extracted. After that, mass of fruit fed into the machine, mass of juice extracted, mass of residual waste and pulp content of the fruit were recorded. Each experiment was replicated three times for fruits. The performance of the pulp extractor was evaluated in terms of pulp yield, extraction efficiency, extraction loss, and machine throughput using the following formulae as suggested by various researchers ((Adebayo et al., 2014; Adonis et al., 2016).).

$$\text{Pulp yield (\%)} = \frac{W_2}{W_1}\times 100 \quad (1)$$

$$\text{Extraction efficiency (\%)} = \frac{W_2}{W_2+W_4}\times 100 \quad (2)$$

$$\text{Extraction loss (\%)} = \frac{W_4}{W_2+W_4}\times 100 \quad (3)$$

$$\text{Machine throughput (\%)} = \frac{W_1}{t} \quad (4)$$

where W_1 is the mass of fresh fruits fed inside, kg

W_2 is the mass of pulp obtained from outlet, kg

W_3 is the mass of skin and seed, kg

W_4 is the pulp not recovered, kg

t is the pulp extraction time, h

Machine throughput = amount of fruits fed for pulping/Pulp extraction time

2.8 Statistical analysis and optimization

The experiments were designed and analyzed using method using Design Expert Software (Version 13.0). A total of 13 experiments were performed with five center points. Experimental data were fitted to a second-order polynomial model, and regression coefficients were obtained. Mathematical models were evaluated for each response by means of multiple regression analysis. Analysis of variance (ANOVA) was applied to test the performance of the machine and find significant terms in the model. The significance level at $p < .001$, judged by the F-value, was calculated from the data. Optimization was necessary to get good result and to have optimum parameters to get the best result. Optimization of the pulper was done by the dependent response such as pulp yield, extraction efficiency, extraction loss, and independent factors like speed of main shaft and feed input using response surface methodology (RSM).

3 Results and discussion

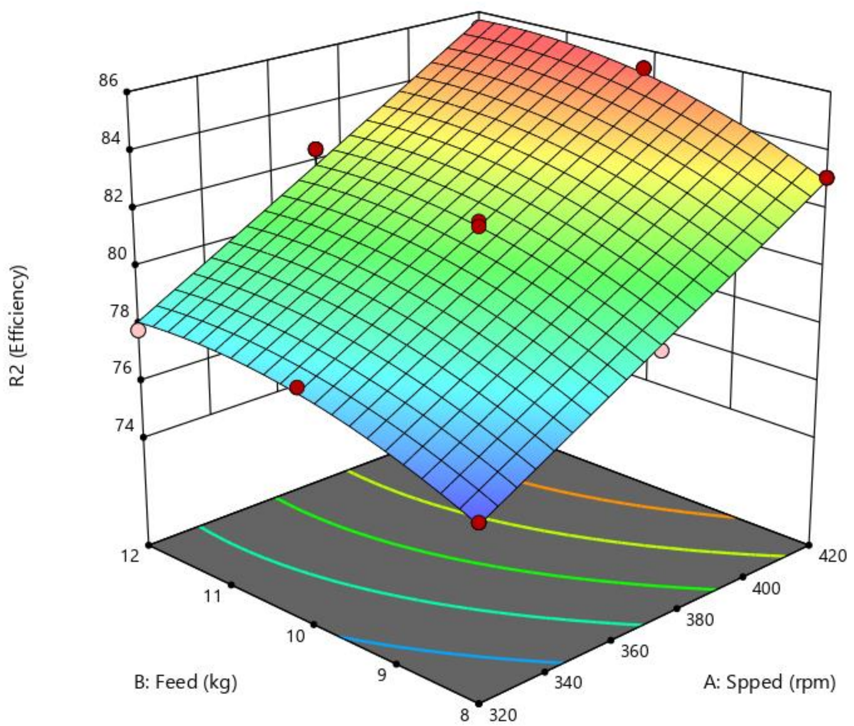
3.1 The developed and fabricated pulper

The specification and size of each component are shown in Table 1. The overall size of the machine is 1.2 m × 1.75 × 1.40 m. The pulper was fabricated by M/s. Sri Venkatapadma Agro Industries, Rajamahendravram (Andhra Pradesh, India). The photographic image of the fabricated machine is shown in Figure 1.

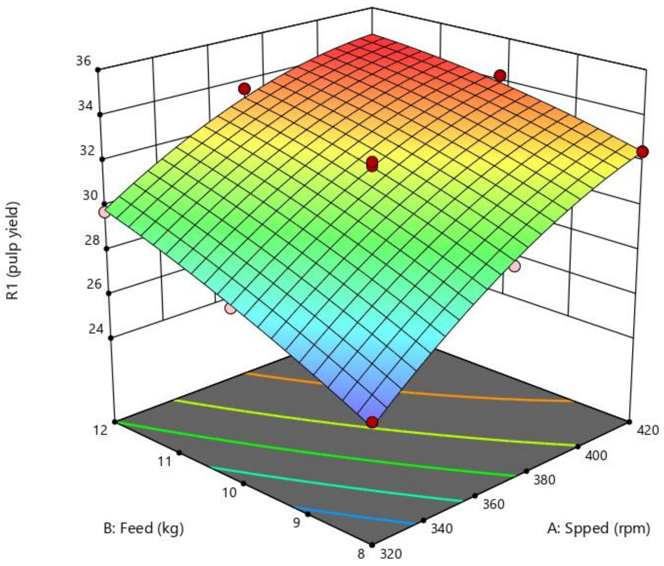
Machine throughput was found out to be 50 kg-hr^{-1}. The tests carried out with fresh Palmyrah fruits showed that pulp could be extracted, and machine can be operated batch wise. The variables are fixed for testing performance of the pulper after preliminary trials as shown in Table 2. Optimization of performance within these ranges of feed and speed was done. Palmyrah fruit with dip for 2 min in hot water followed by peeling, and operation time for maximum extraction pulp from the fruit was 6min with farward and backword rotation of the main shaft.

3.2 Effect of speed and input on testing indices

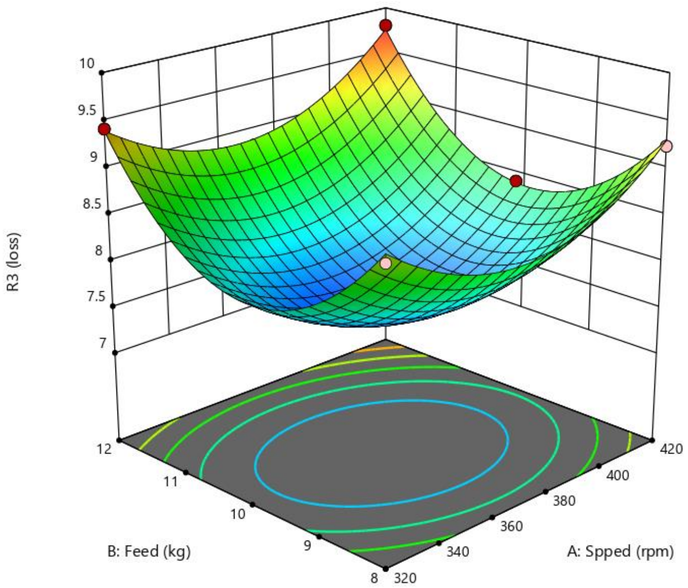
Variation of performance indices such as pulp yield, extraction efficiency, and extraction loss of the pulper with respect to varied speed and input shown in Figure 3. Speed and feed input significantly ($p < .001$) affected pulp yield and overall machine throughput. The average pulp content of Palmyrah fruit was 40%. The pulp yield ranged between 25.24% and 35.42% on weight basis of the whole fruit. Some amount of pulp remained in the machine may be because of its higher stickiness due to intact fibrous material. The effects of speed, and input on extraction efficiency of the pulper are shown in Figure 3b. The experimental value of extraction efficiency ranged between 75.98% and 85.42%. Extraction loss (Figure 3) ranged between 7.5% and 9.8%. At lower speed, the fruits were not crushed properly and resulted in clogging of the machine resulting in lower extraction and higher loss. These results are in agreement with the findings for pineapple juice extractor (Adebayo et al., 2014) and kendu pulper (Hmar et al., 2017). The extraction efficiency of the pulper increased with an increase in speed at the initial stage and decreased later. This can be attributed to lesser contact time between the crushed fruit resulting in lesser pulping efficiency (Hmar et al., 2017: Thirupathi et al., 2006).



(a) Pulp yield, %



(b) Extraction Eefficiency, %



(c) Extraction Efficiencyloss, %

Figure 3 Response surface graphs for all three dependent responses

3.3 Models generated from machine testing

The results were fitted in polynomial quadratic models. Regression coefficients of the proposed models and statistical significance for each response were calculated. ANOVA of the results for all parameters such as pulp yield, extraction efficiency, and extraction loss suggested significance of each response at $p < .001$ as shown in Tables 3–5. The proposed quadratic/polynomial models were suitable with R2 and predicted R2 higher than 0.9 for all the responses. The perturbation graph (Figure 4) suggested high sensitivity of the responses to independent factors (i.e., speed and input). The pulp yield and extraction efficiency have positive relations and extraction loss has negative relation with the independent factors. The response surface models for various performance indices are as below. The coefficient of variance for each of the models was less than 5% and was having acceptable repeatability.

Pulp yield $= 31.77+ 3.08\ A +1.78\ B - .645\ AB- 0.925\ A^2-0.325\ B^2$

Extraction efficiency $= 81.45+ 3.67\ A +1.23\ B +0.11AB+0.031\ A^2-0.798\ B^2$

Extraction loss $= 7.59+ 0.136A +0.185\ B + 0.04\ AB+ 0.68\ A^2+ 1.13\ B^2$

where A is the speed of shaft, (rpm) and B is the Input, (kg) of palmyrah fruit.

Table 3 ANOVA for response surface quadratic model for pulp yield

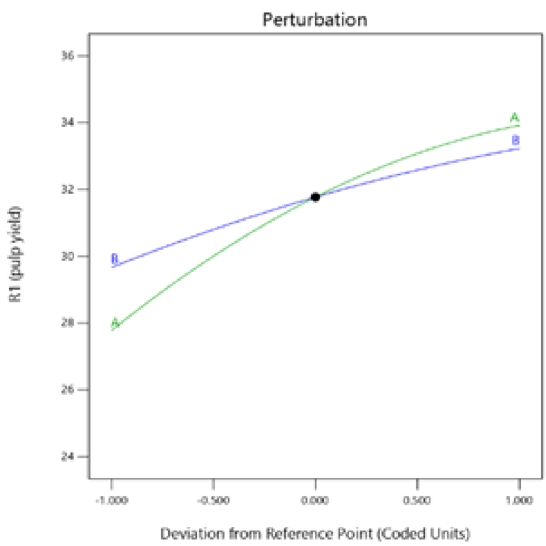
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	81.40	5	16.28	125.63	< 0.0001	significant
A-Spped	56.80	1	56.80	438.29	< 0.0001	
B-Feed	19.08	1	19.08	147.25	< 0.0001	
AB	1.66	1	1.66	12.84	0.0089	
A^2	2.37	1	2.37	18.27	0.0037	
B^2	0.2933	1	0.2933	2.26	0.1762	
Residual	0.9071	7	0.1296			
Lack of Fit	0.5004	3	0.1668	1.64	0.3148	not significant
Std. Dev.	0.3600		R^2	0.9890		
Mean	31.20		Adjusted R^2	0.9811		
C.V. %	1.15		Predicted R^2	0.9329		

Table 4 ANOVA for response surface quadratic model for extraction efficiency

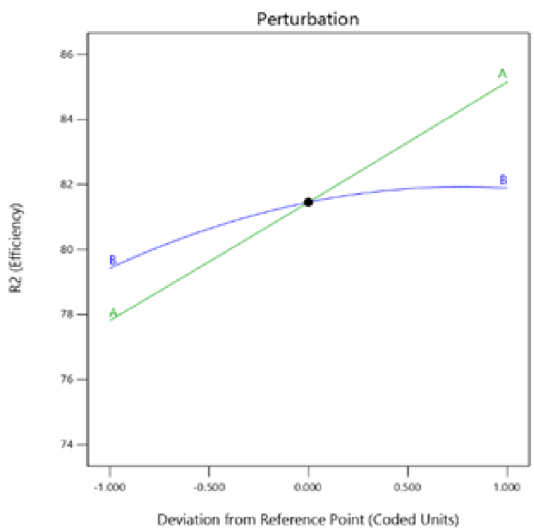
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	92.09	5	18.42	149.24	< 0.0001	significant
A-Spped	80.96	1	80.96	656.06	< 0.0001	
B-Feed	9.08	1	9.08	73.56	< 0.0001	
AB	0.0484	1	0.0484	0.3922	0.5510	
A^2	0.0028	1	0.0028	0.0225	0.8849	
B^2	1.76	1	1.76	14.26	0.0069	
Residual	0.8638	7	0.1234			
Lack of Fit	0.6531	3	0.2177	4.13	0.1020	not significant
Std. Dev.	0.3513		R^2	0.9907		
Mean	81.10		Adjusted R^2	0.9841		
C.V. %	0.4332		Predicted R^2	0.9331		

Table 5 ANOVA for response surface quadratic model for extraction loss

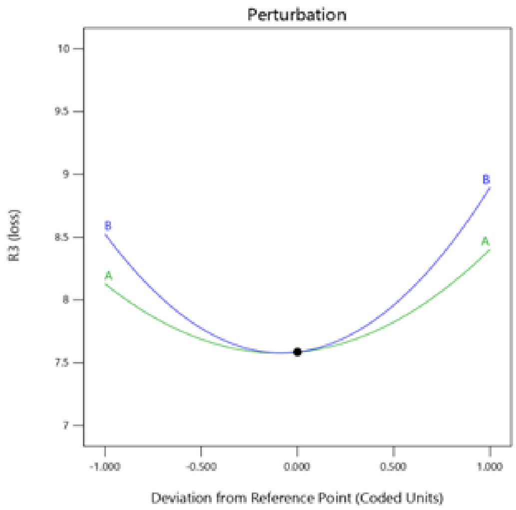
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	7.80	5	1.56	135.77	< 0.0001	Significant
A-Spped	0.1121	1	0.1121	9.75	0.0168	
B-Feed	0.2053	1	0.2053	17.87	0.0039	
AB	0.0064	1	0.0064	0.5570	0.4798	
A^2	1.28	1	1.28	111.37	< 0.0001	
B^2	3.50	1	3.50	304.57	< 0.0001	
Residual	0.0804	7	0.0115			
Lack of Fit	0.0496	3	0.0165	2.14	0.2379	not significant
Std. Dev.	0.1072		R^2	0.9898		
Mean	8.42		Adjusted R^2	0.9825		
C.V. %	1.27		Predicted R^2	0.9350		



(a) Pulp yield, %



(b) Extraction Eefficiency, %



(c) Extraction Efficiencyloss, %

Figure 4 Perturbation graph for all three dependent responses

3.4 Optimization results

Optimum operating conditions for palmyrah pulper were determined RSM for selected ranges of speed and feed rate (Table 2). The ideal conditions were to get maximum pulp yield and extraction efficiency with minimum extraction loss. The desirability function analysis suggested optimum values of speed and feed rate as 264.58 rpm and 2.41 kg-min^{-1}, respectively, with a desirability value of 0.929 (Adebayo et al., 2014). When the machine was operated at optimum conditions, the pulp yield, extraction efficiency, and extraction loss of the pulper were 36.04%, 78.36%, and 19.17% respectively. In practice, it is difficult to adopt the fractional values of optimized operating conditions. Hence, the suggested operating conditions such as speed and feed rate are 260 rpm and 2.5 kg-min^{-1}, respectively. Similar extraction efficiencies of 75% and 71% have been reported for pineapple and melon juice extractors, respectively (Adonis et al., 2016; Eyeowa et al., 2017).

4 Conclusion

A small-scale pulper was developed for Palmyrah fruit, a neglected fruit from plantation crops. The operating conditions such as speed and input of the pulper for maximum extraction and minimum loss were optimized. The testing indices such as pulp yield, extraction efficiency, and extraction loss of the pulper were 33.90%, 84.78% and 8.25%, respectively. Response surface models for operation of the pulper were developed with the highest repeatability as suggested by the coefficient of variance lesser than 5%. The desirability function analysis suggested optimum values of speed and feed rate as 412.33 rpm and 10.33 kg of fruits for batch for 6 minutes of operation respectively with a desirability value of 0.892. The suggested operating conditions such as speed and input are 410 rpm and 10 kg for batch. The operation and maintenance of the designed pulper were easy. This would certainly increase the commercial use of the fruit and boost income generation to support the livelihood of rural people.

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