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Optimization of Machine Parameters for the Peeling of a Commercial Abrasive Peeler for Mother Corm (*Colocasia esculenta*)

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Authors' contributions

This work was carried out in collaboration among all authors. Author CKN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SKD and KR managed the analyses of the study. Author KR managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The purpose of this study was to optimize the machine parameters of a commercially available tuber peeler for the peeling of mother corms.
Study Design: CCRD (Central composite rotatable design) method of the response surface methodology (RSM) technique.
Place and Duration of Study: Department of Agricultural Processing and Food Engineering, College of Agricultural Engineering and Technology, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha (India), between June 2021 and December 2021.

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Methodology: For maximum yield with minimum loss, the process was conducted with three different variables such as rotating disc speed (350, 450 and 550 rpm), peeling duration (60, 120 and 180 sec) and batch load (1, 1.5 and 2 kg) for responses such as peeling efficiency (η_p), material loss (ML) and peeling effectiveness (PE).

Results: The results showed that peeling performance was influenced by variations in disc speed, peeling duration, and batch load of the peeling process. Rotating disc speed of 455 rpm, peeling duration of 115 sec and 1.35 kg of batch load were found to be the optimum condition for taro corm peeling. The corresponding peeling efficiency, peeling effectiveness and material loss were 92.64 %, 84.87 % and 8.21% respectively.

Conclusion: This study showed that the method can be successfully utilized in the commercial processing of mother corms.

Keywords: CCRD; abrasive type peeler; peeling efficiency; material loss; peeling effectiveness; batch load.

1. INTRODUCTION

Taro (*Colocassia esculenta* L.) is an *Araceae* family tuber crop that is widely grown for its underground edible corms [1]. Similar to yams, taro corms are a common food source in South Asia, Africa, and Oceania [2]. Over the previous 30 years, taro root production has steadily increased, reaching 10.54 million tonnes in 2019 [3]. Nigeria, Cameroon, China, Ghana, and Papua New Guinea are the top 5 producers, with production totaling 2.86, 1.909, 1.908, 1.51, and 0.27 million tonnes in 2019 [3]. Even with taro's nutritional, health Taro's common names can vary from island to island and country to country, and even the same cultivar can have different names in different countries. As a result, proper identification between different cultivars is quite difficult [4].

Mother corms refer to the main underground storage structures of the taro plant (*Colocasia esculenta*). Taro is a tropical plant widely cultivated for its edible corms, which are also known as "taro roots." The corm is the swollen base of the stem where the plant stores nutrients and energy. Taro corms are typically large and starchy, with a brown or purplish outer skin and a white, pink, or yellowish flesh inside. They have a nutty flavour and are commonly used in various culinary preparations, particularly in Asian and Pacific Island cuisines. In traditional farming practices, taro corms are harvested when mature, and a portion of the corms is usually kept aside as "mother corms" for propagation in the next growing season. These mother corms are replanted to produce new taro plants, allowing farmers to sustain the cultivation of taro over time.

Mother corms vary in size and shape depending on taro variety, growing conditions, and regional preferences. They are round or oval-shaped, with a swollen appearance, and have brown or purplish outer skin. The flesh colour ranges from white to pinkish or yellowish, and is dense and starchy. The texture is firm and solid, with a smooth, creamy consistency when cooked. These are rich in carbohydrates, dietary fiber, minerals, and vitamins. They can undergo value-addition processes to enhance their culinary and commercial value. They are primarily used for propagation and food processing, including peeled, sliced, and ground taro for dishes, flour, and beverages [5]. These can also be used in fermentation processes to produce traditional foods and condiments. Value addition methods may vary depending on cultural practices, market demands, and processing facilities.

Mother corms are valuable for propagation but can suffer from damage or disease during storage or transportation. Improper storage conditions can cause spoilage or rotting, leading to significant losses. Harvesting, cleaning, storing, and maintaining corms incur operational costs, and inefficient management practices can lead to financial losses. Minimizing losses through proper handling, storage, disease management, and market analysis can ensure a favourable return on investment. Good agricultural practices, quality control measures, and market awareness can optimize taro mother corm utilization.

Peeling is an important aspect in the food processing, and most agricultural products must be peeled at the initial stage of food processing [6]. The amount of calcium oxalate raphides decreases from the outer skin to the centre of the corm [7]. Thus, removal of the outer skin helps reducing the acridity of the corms and improves its nutritional value. However, tuber processing, particularly peeling, is typically labour-intensive, time-consuming and inefficient method. Among available peeling the methods, the mechanical method has advanced the most, but the end goal is to design an efficient and effective peeling process for mother corms. Only some taro corm peeling machines have been developed [8-10] as a consequence of research efforts, but their performance, particularly peeling efficiency, is quite low. This requires the study of traditional methods of removing mother corm peels in order to develop a model machine that can mechanically peel taro tubers of all sizes, shapes, and weights. In the view of this the present study makes an effort to study the different operational parameters of a commercially available peeler for mother corm with the objective to develop a mother corm peeling process with good peeling performance.

2. MATERIALS AND METHODS

2.1 Materials

Freshly harvested mother corms (*Colocasia esculenta*), of the variety *Muktakeshi,* were procured from the ICAR-CTCRI Regional Centre, Bhubaneswar during December 2021. For the study, the corms were sorted manually into uniform grades and their length, breadth, and thickness were measured to be 6.9 ± 1.54 cm, 5.8 ± 1.07 cm, and 4.43 ± 1.02 cm, respectively (Fig. 1). Corms that were too small, infested, or damaged were not considered. The moisture content was found to be around 278 ± 2.16 % (db).

2.2 Machine Description

Taro corms were peeled using an abrasive type tuber (potato) peeling machine (Fig. 2). The machine has a cylindrical peeling drum (1) with peeling chamber of 0.0276 m3 volume and a revolving disc (2). All of these are supported by a mild steel metal framework (3). A circular feed inlet of 8 cm diameter (4) is provided at the top of the drum for feeding purpose. Water is continuously supplied during the peeling process by an inlet pipe (5) with an inner diameter of 0.8 cm. An abrasive coating of coarse carborundum (approximately 1-2 cm thick) is provided on the upper surface of the revolving disc to help remove the corm skin. The peeled skin, tuber debris, and water pass through three ripples given over the revolving disc and are removed by a drain pipe (6) of diameter of 6 cm and a length of 30 cm. After peeling, the peeled tuber is taken through the outlet (7) having dimensions of 15 x 15 cm. A DC electric motor (8) coupled with a battery charger (AC to DC convertor) (9) operates the revolving disc via a belt mechanism. One AC voltage variant, or variac, regulates the rotational speed of the disc (10).

During the experiments the variac speed required to produce the desired disc rotation was measured using a digital tachometer (KM-2241, Kusam-Meco, India). The capacity of the peeler for mother corms was around 35-50 kg/h (bulk density of 516 kg/m^3).

Fig. 1. Samples of mother corms used in the study

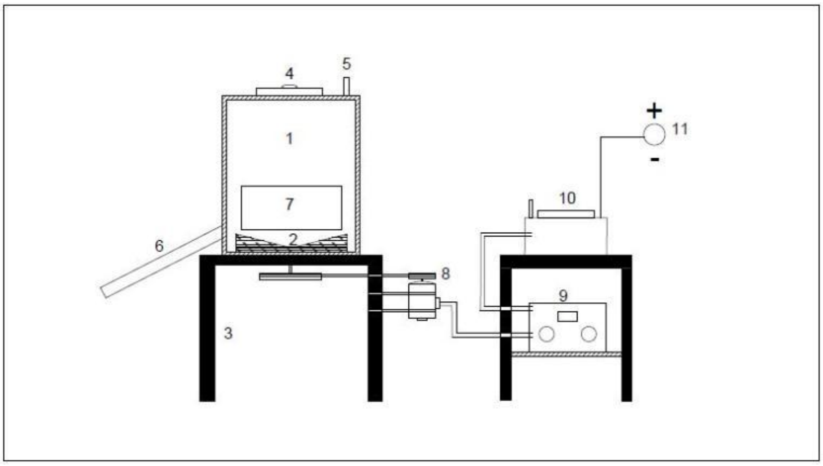


Fig. 2. Experimental setup of the peeling unit

1. Peeling drum 2. Rotating disc, 3. Metal framework, 4. Tuber inlet, 5. Inlet pipe, 6. Drain pipe, 7. Tuber outlet, 8. DC electric motor, 9. Battery charger, 10. AC variac, 11. AC power source

2.3 Experimental Plan

Peeling experiments were planned in order to study the effect of operational parameters on desirable peeling of mother corms with minimal material loss. The experiments were conducted with a rotating disc diameter of 34.5 cm at different rotating disc speeds of 350 ± 5, 450 ± 5 and 550 ± 5 rpm (6.3, 8.12 and 9.93 m/s) and peeling durations of 60, 120 and 180 sec. These levels were decided through preliminary studies. Practically, peeling with full capacity of the peeler is not recommended due to the reduced effectiveness of the operation. Hence, the effect of batch load was also considered of three level, viz. 1 kg, 1.5 kg and 2 kg, which were approx. 7.5%, 11.25% and 15% of the total capacity (for tubers with a density of 461 kg/m^3). According to preliminary research, batch loads above or below this range resulted in breakage of corms into pieces before effective peeling was obtained. This further caused increased material loss as the open surface of the broken pieces was subjected to abrasion. The peeling performance was evaluated as peeling efficiency (η_p), material loss (ML), and peeling effectiveness (PE). Prior to the experiments, theoretical peel and flesh percentages (based on raw corm) were determined by carefully removing the peels manually with a knife.

The different peeling quality factors were calculated using Eqs. (1) - (5). In Eq. (5), the ML and η_p are expressed in decimals [11].

$$\text{Actual peel content, } P_{th}\ (\%) = \frac{M_{thp}}{M_t} \times 100 \quad (1)$$

$$\text{Actual flesh content, } F_{th}\ (\%) = \frac{M_t - M_{thp}}{M_t} \times 100 \quad (2)$$

$$\text{Peeling efficiency, } \eta_p\ (\%) = \frac{(M_{sp} \times P_{th}) - M_{rp}}{(M_{sp} \times P_{th})} \times 100 \quad (3)$$

$$\text{Material loss, ML } (\%) = \frac{(M_{sp} \times F_{th}) - (M_{psp} - M_{rp})}{(M_{sp} \times F_{th})} \times 100 \quad (4)$$

$$\text{Peeling effectiveness, PE } (\%) = (1 - ML) \times \eta_p \times 100 \quad (5)$$

Where P_{th}, is theoretical peel content; M_{thp}, weight of peel obtained by manual peeling (theoretical peel weight); M_t, weight of corms taken for manual peeling; F_{th}, theoretical flesh content; η_p, peeling efficiency; ML, material loss; M_{sp} , weight of taro corms fed into the peeler; M_{rp}, weight of peel retained on the peeled tuber collected at the outlet of the peeler; and M_{psp}, weight of peeled taro corm obtained at the outlet of the peeler.

2.4 Statistical Modelling, Data Analysis, and Optimization

RSM is a technique that is suitable for fitting a quadratic surface and it helps in the optimization of process parameters with least number of experiments, as well as in analysing the interaction among the parameters [12]. It is one of the economic methods for statistical data analysis, studying parameter effects and the development of an empirical model [13]. In this study, the Central Composite Rotatable Design (CCRD) with three parameters at different levels was used, to minimise the number of experiments and to optimise the peeling conditions.

The study aimed to optimize mother corm peeling process parameters using a rotating disc speed of 350-550 rpm, a peeling duration of 60-180 sec, and a peeler batch load of 1-2 kg. The Design Expert software package Version 10.0.3 (Stat-Ease, Statistics Made Easy, Minneapolis, MN, USA) was used for regression analysis, and the results were validated using ANOVA and F-test. The canonical and maximum ridge analysis were employed to optimize the peeling process parameters.

3. RESULTS AND DISCUSSION

3.1 Standardization of Operational Parameters for Peeling of Mother Corm

The peel and flesh contents in mother corms were 16.34 ± 0.71% and 84.66 ± 0.93%, respectively. The peeling efficiency (η_p), material loss (ML) and peeling effectiveness (PE) obtained for manual peeling of mother corms were 97.44 ± 0.62%, 0.064 ± 0.013% and 91.20± 0.43%, respectively. It was observed that the manual peeling of mother corm took about 35-40 min per kg of raw material.

The major independent parameters considered in this study were rotating disc speed, peeling duration and batch load, as given in Table 1 with their levels (5 levels). The complete CCRD design of experiment with number of runs and combination of levels of parameters is given in Table 2. The values of responses with process parameters in actual and coded levels for different experimental runs (20 numbers) of the peeling process are presented in Table 2.

The study analyzed experimental data to understand the impact of independent parameters on peeling process response parameters. Linear and second-order models were fitted, and ANOVA was performed to identify significant effects of process or independent parameters on dependent parameters. The effects of operational parameters on peeling performance parameters such as η_p, ML and PE are explained in the subsequent sections.

3.2 Effect of Process Parameters on Peeling Efficiency (η_p) of Mother Corm

The η_p varied from 57.55 to 95.74% with different combinations of processing parameters. The highest value of peeling efficiency (95.74 %) was obtained for the independent parameter combination given in std run no. 17 (Table 3). The highest η_p was obtained at rotating disc speed of 450 rpm along with the peeling duration of 120 sec. On the other hand, the minimum value of η_p was recorded for the rotating disc speed of 280 rpm, peeling duration of 120 sec and batch load of 1.5 kg.

Table 1. Levels of different parameters used in CCRD during the peeling of mother corm

Independent Variable	Symbol	Levels of coded variables				
		- α	**Low**	**Medium**	**High**	**+ α**
		-1.68	**-1**	**0**	**1**	**+1.68**
Rotating disc speed (rpm)	A	281.82	350	450	550	618.18
Peeling duration (sec)	B	20	60	120	180	220
Batch load capacity (kg)	C	0.66	1	1.5	2	2.34

Table 2. Experimental factors in coded and actual forms and experimental responses for peeling of mother corms

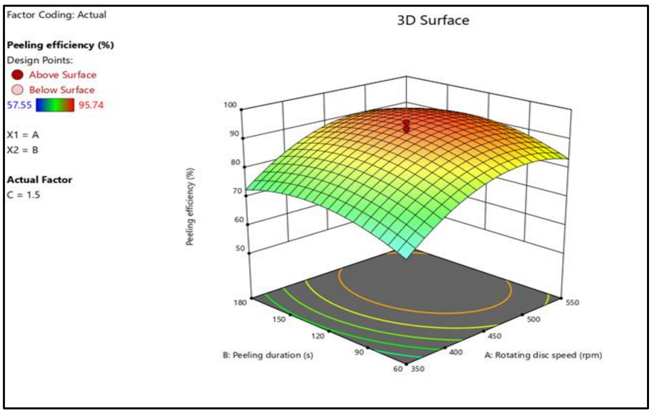
Std run no.	Run	Independent variable in coded form			Independent variable in actual form			Peeling efficiency (%)	Material loss (%)	Peeling effectiveness (%)
		A	B	C	Rotating disc speed (rpm)	Peeling duration (sec)	Load capacity (kg)			
1	17	-1	-1	-1	350	60	1	64.21	9.84	57.89
2	16	1	-1	-1	550	60	1	83.54	16.27	69.94
3	7	-1	1	-1	350	180	1	72.47	13.08	62.99
4	3	1	1	-1	550	180	1	89.51	28.14	64.32
5	6	-1	-1	1	350	60	2	62.11	14.18	53.3
6	1	1	-1	1	550	60	2	78.04	19.98	62.44
7	11	-1	1	1	350	180	2	67.05	21.29	52.77
8	13	1	1	1	550	180	2	82.98	31.04	57.22
9	18	- α	0	0	280	120	1.5	57.55	13.07	50.02
10	9	+ α	0	0	620	120	1.5	78.66	34.08	51.85
11	20	0	- α	0	450	20	1.5	75.35	10.07	67.76
12	10	0	+ α	0	450	220	1.5	79.41	17.27	65.69
13	15	0	0	- α	450	120	0.65	89.21	15.12	75.72
14	19	0	0	+ α	450	120	2.35	85.41	19.03	69.15
15	4	0	0	0	450	120	1.5	91.06	5.1	86.49
16	14	0	0	0	450	120	1.5	90.68	8.51	82.96
17	2	0	0	0	450	120	1.5	95.74	9.24	86.89
18	5	0	0	0	450	120	1.5	89.21	9.03	81.15
19	8	0	0	0	450	120	1.5	93.55	10.07	84.12
20	12	0	0	0	450	120	1.5	92.11	8.94	83.87

Table 3 gives the analysis of variance of η_p for fitting the quadratic model to experimental data. It can be observed that the regression model for η_p was found to be statistically significant at 97% level of confidence. It is also observed that the combined effects of all the independent parameters except interactions were significant at linear and quadratic levels. The ANOVA gives that the lack of fit for the η_p model, which is non-significant at confidence level of 94.51 % (adjusted R^2). Additionally, the values of R^2, adjusted R^2 and coefficient of variation (CV) have been determined to check the adequacy of the regression model. The high level of variability (R^2> 95%) in the response (η_p) can be adequately explained by the model. The empirical model (Eqn. 6) in terms of coded factors was obtained to express the relationship between the independent parameters and η_p.

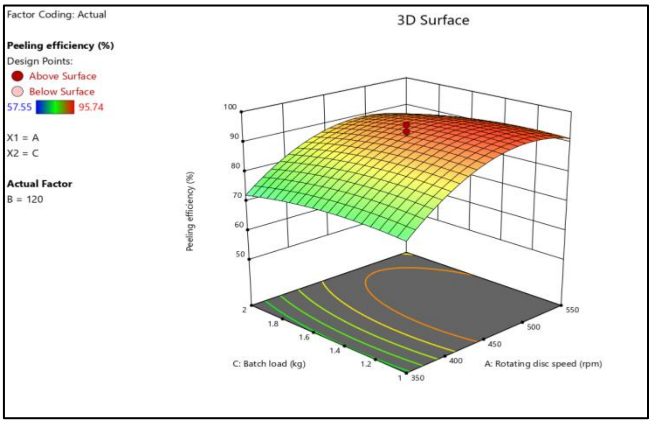
$$\eta_p\ (\%) = +92.11 + 7.60A + 2.27B - 1.90C - 8.83A^2 - 5.56B^2 - 2.04C^2 \quad (6)$$

(R^2 = 0.97)

Table 3 and the developed coded regression equation for η_p (Eqn. 6) reveal that rotating disc speed, peeling duration, and batch load, all had a significant effect on η_p at the linear level $P \leq .001$, $P \leq .05$ and $P \leq .05$ respectively. The coefficients of linear terms of the developed equation (Eqn. 4.4) further indicate that the rotating disc speed had the highest (7.60) positive influence on the η_p followed by peeling duration (2.27), while batch load capacity (-1.90) negatively influenced at linear level. The P value indicates that all interaction terms had no significant effect ($P < .05$) on η_p. The quadratic effect of rotating disc speed was highly significant ($P < .001$), followed by quadratic effect of peeling duration ($P \leq .001$) and batch load ($P \leq .05$). It is important to note that the quadratic effect of all variables had a negative effect. This implies that higher levels of these parameters decreased the η_p values.



(a)



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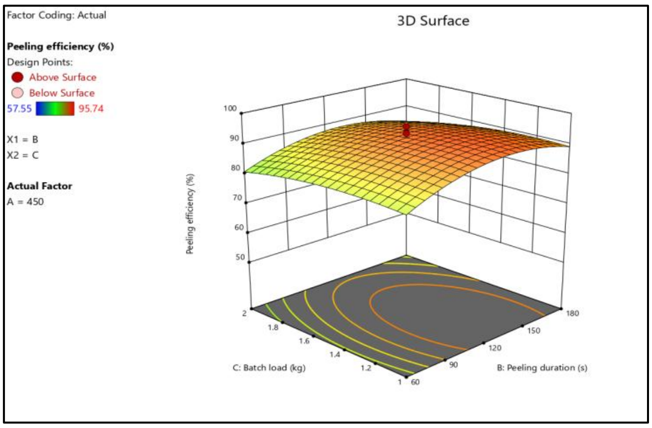


(c)

Fig. 3. Response surface plots for peeling efficiency with two parameter

In order to illustrate the cumulative effects of the two factors on the response parameter (η_p), response surfaces and contour plots were developed for the fitted model with two independent parameters, one of which was maintained at the mid values.

Fig. 3 (a–c) shows the surface plots of η_p as affected by rotating disc speed, peeling and batch load. The results suggest that the η_p increases as the rotating disc speed and peeling duration increase up to the optimum (450 rpm and 120 sec), then starts decreasing. It can be seen that the rotating disc speed and peeling duration were the major parameters influencing the process. A similar increase in η_p with peeling speed was reported by Balami et al. [8] and Olukunle and Akinnuli [14] for taro and cassava tubers. The increase of η_p up to 450 rpm and 120 sec is attributed to longer contact of tubers with the abrasive surface that caused the removal of more peel [15]. However, Daniyan et al. [16] also observed similar research for cassava tubers, where a further increase in peeling time, beyond the optimum duration reduced the η_p.

The value of η_p also increased with the batch load from 1 to 2 kg. A similar finding was also reported by Singh and Shukla [15]; Olukunle and Akinnuli [14] and Fadeyibi and Faith Ajao [10], in which there was increase in peeling efficiency with batch load until a specific duration of peeling, beyond which it decreased due to over peeling of some tubers and under-peeling of others. For good peeling efficiency, the mother corm tubers require proper size-based sorting before peeling.

3.3 Effect of Independent Parameters on Material loss (ML) of Mother Corm

The material loss (ML) ranged between 5.1 and 34.08% with different combinations of process parameters (Table 2). The highest value of ML (34.08%) was obtained for the parameter combination of rotating disc speed of 620 rpm, peeling duration of 120 sec and batch load of 1.5 kg. The minimum value was for the operational combination of rotating disc speed of 450 rpm, peeling duration of 120 sec and batch load of 1.5 kg.

Table 3 gives the ANOVA of ML for fitting the quadratic model to experimental data. The developed regression model for ML was found to be statistically significant at 97% confidence level. It is also observed that the all interaction terms have no significant (P > .05) effect on the ML of mother corms. The lack of fit for the ML model is not significant at confidence level of 92.74 % (adjusted R^2). The regression model in terms of coded factors was obtained to express the relationship between the independent parameters and ML (Eqn.7).

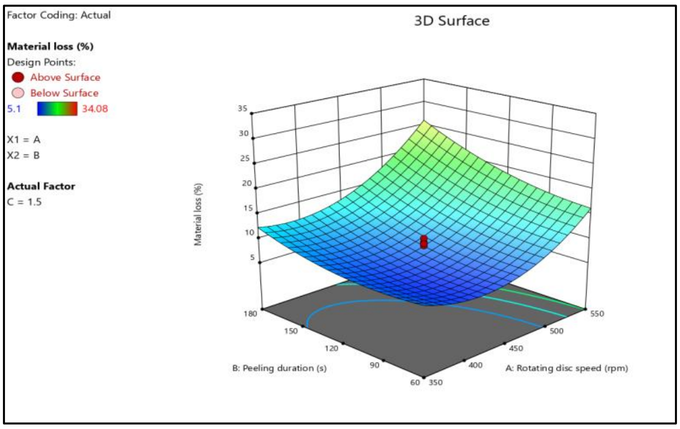
$$ML\ (\%) = 8.46 + 5.30A + 3.32B + 1.88C + 1.57AB + 5.45A^2 + 1.95B^2 + 3.15C^2 \quad (7)$$

(R^2 > 97%)

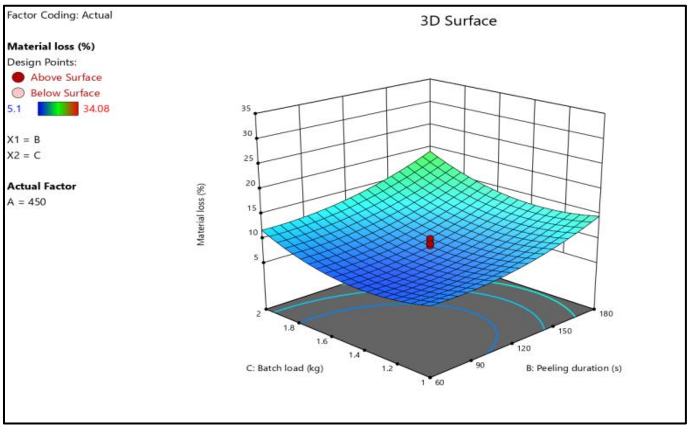
Table 3. ANOVA for the effect of process parameters on peeling efficiency, material loss and peeling effectiveness of mother corm

Source	Peeling efficiency (%)		Material loss (%)		Peeling effectiveness (%)	
	P value	Regression coefficient	P value	Regression coefficient	P value	Regression coefficient
Model	< 0.0001*		< 0.0001*		< 0.0001*	
A	< 0.0001*	7.60	< 0.0001*	5.30	0.0151**	2.20
B	0.0102**	2.27	0.0002*	3.32	0.3641^{ns}	-1.71
C	0.0245**	-1.90	0.0087**	1.88	0.0028*	-2.96
AB	0.7665^{ns}	-0.29	0.0646***	1.57	0.0780***	-1.93
AC	0.5612^{ns}	-0.56	0.3501^{ns}	-0.74	0.9792^{ns}	0.03
BC	0.5749^{ns}	-0.54	0.6245^{ns}	0.38	0.5203^{ns}	-0.65
A^2	< 0.0001*	-8.83	< 0.0001*	5.45	< 0.0001*	-12.20
B^2	< 0.0001*	-5.56	0.0062**	1.95	< 0.0001*	-6.61
C^2	0.0152**	-2.04	0.0002*	3.15	< 0.0001*	-4.60
Lack of Fit	0.3031^{ns}		0.2246^{ns}		0.1923^{ns}	
Statistical Measures						
R^2	0.97		0.96		0.97	
Adjusted R^2	0.94		0.93		0.95	
Predicted R^2	0.84		0.78		0.85	
APR	20.12		16.11		19.46	
CV(%)	3.28		13.68		4.06	

*ns- non-significant; * significant at .001 level; ** significant at .05 level; ***significant at 0.1 level. A: Rotating disc speed; B: peeling duration: C: batch load.*



(a)



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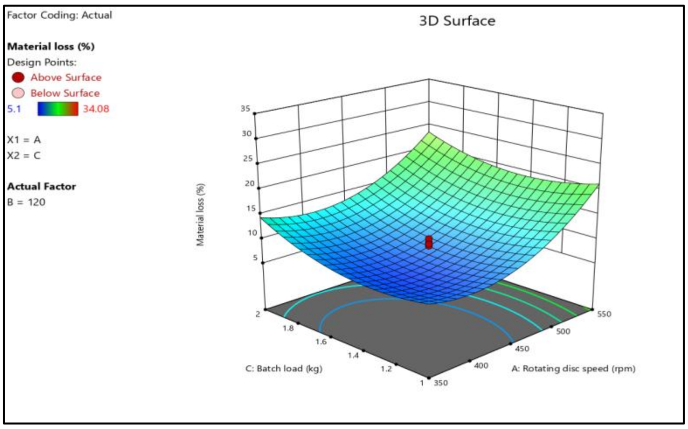


(c)

Fig. 4. Response surface plots for material loss with two parameters

From the ANOVA (Table 3), it is observed that rotating disc speed, peeling duration and batch load significantly affected the ML at the linear level $P \leq .001$, $P \leq .05$ and $P \leq .05$ respectively. Further, the positive coefficient of rotating disc speed (Eqn. 7) being maximum (5.30) among the linear terms suggested that it had the most positive influence on the ML, followed by peeling duration (3.32) and batch load (1.88). It is also observed that the interaction terms of rotating disc speed and peeling duration has significant (*P* ≤ 0.1) effect on the ML of mother corms (Table 3). The quadratic effects of rotating disc speed (*P* < .001), peeling duration (*P* < .05) and load capacity (*P* < .05) were highly significant, whereas the process resulted in a comparatively higher (5.45) quadratic effect of rotating disc speed. The quadratic effects of rotating disc speed, peeling duration and batch load had a positive significant effect on ML, indicating a positive contribution to increase in their levels.

Fig. 4 (a–c) shows the response surfaces of ML as affected by rotating disc speed, peeling duration and batch load. The material loss initially decreased with rotating disc speed and peeling duration up to the optimum levels (450 rpm and 120 sec). Beyond the optimum level, it started to increase, which may be attributed to the loss of flesh portions caused by less frequent contact of tubers with abrasive surfaces at higher speeds and for longer durations of peeling. Fadeyibi and Faith Ajao [10] and Nathan et al. [17] also reported higher mechanical damage (excessive shearing stress) to the tubers at higher peeling speeds, which in turn decreased the mass of peeled tubers.

It was also observed that material loss was lowest at 120 sec, followed by 60 sec and 180 sec. Beyond the optimum duration (120 sec), ML loss was continuously increased as peeling duration increases. It was also seen that ML decreased up to the optimum (1.5 kg) with the batch load, but beyond that, it started increasing. This may be due to the grating effect of the machine when the optimum speed and time are exceeded [16]. This was similar to the previous results reported for potato at batch loads of 5–20 kg [15]. This is attributed to the over- and under-peeling of some tubers as the load density increased.

3.4 Effect of Independent Parameters on Peeling effectiveness (PE) of Mother CORM

The peeling effectiveness (PE) was recorded from 50.02 to 86.89% with different combinations of process parameters (Table 2). The highest value of PE (86.89%) was obtained for the operational parameter combination of rotating disc speed of 450 rpm, peeling duration of 120 sec and batch load of 1.5 kg, and the minimum value for the combination of rotating disc speed of 280 rpm, peeling duration of 120 sec and batch load of 1.5 kg. It could further be seen that the magnitude of PE was comparatively quite lower than the η_p for all the process parameters.

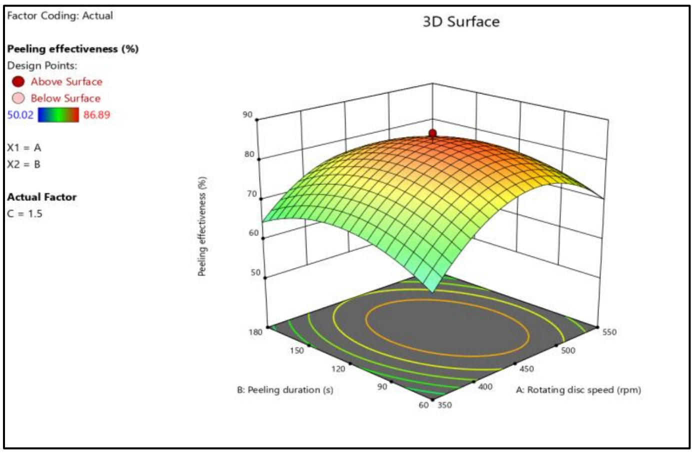
The ANOVA for PE of fitting the quadratic model to experimental data is shown in Table 3. The PE regression model was found to be statistically significant at 97 % level of significance. The lack of fit for the PE model is not significant at confidence level of 95.11% (adjusted R^2). The regression model in forms of coded factors was obtained to express the relationship between the independent parameters and PE (Eqn. 8).

$$PE\ (\%) = 84.31 + 2.20A - 2.96C - 1.93AB - 12.20A^2 - 6.61B^2 - 4.60C^2 \quad (8)$$

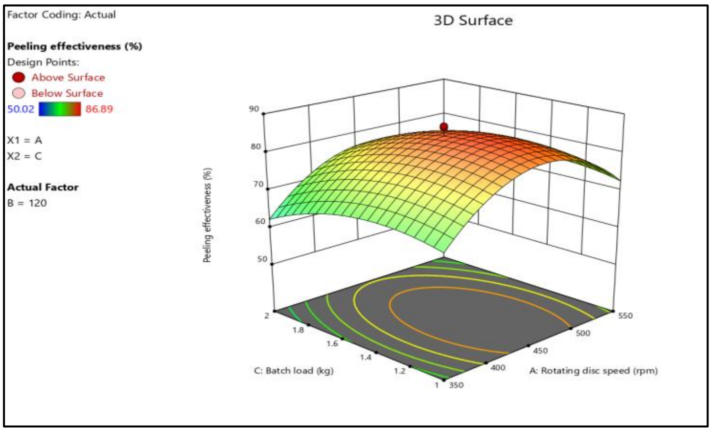
($R^2 = 0.97$)

The regression analysis and the regression equation developed for PE (Eqn. 8), confirms that rotating disc speed (*P* ≤ .05) and batch load (*P* ≤ .001) had a significant impact on PE, while peeling duration was found to be non- significant (*P* > 0.1) effect at the linear levels. Furthermore, the regression coefficient of rotating disc speed (Eqn. 8) was the highest (2.20) among all linear terms; it had the highest positive influence on the PE, while batch load (-2.96) had the negative influence on the PE. All of the interaction effects except the effect of rotating disc speed and peeling duration (*P* < 0.1) were found to be non-significant (*P* > 0.1) for the PE (Table 3). The quadratic effects of rotating disc speed, peeling duration and batch load were highly significant at *P* < .001, *P* < .001 and *P* < .001, respectively, whereas the process resulted in a relatively higher (-12.20) quadratic effect of rotating disc speed. All of the quadratic effects of the three parameters had negatively significant effects on PE, indicating that a negative contribution was made to the response by an excessive increase in their levels.

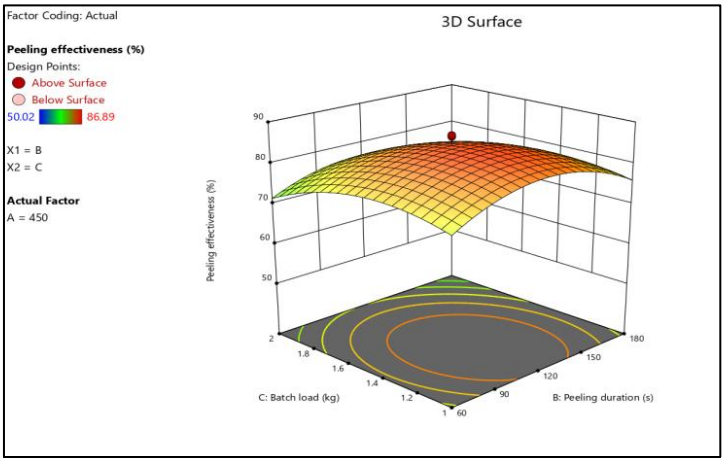
Fig. 5 (a–c) shows the response surface of PE as affected by rotating disc speed, peeling duration and batch load. It is observed that the peeling effectiveness was highest at 450 rpm, which was followed by 350 and 550 rpm. Similarly, PE increased as peeling duration increased from 60 to 120 sec, after which it reduced at 180 sec. The trend of PE is similar to the trend of peeling efficiency for batch loads. This may be attributed to the surface characteristics of the tuber and the non-uniform peeling of tubers at higher load density. Moreover, the relative differences in tuber size within a lot might have influenced the peeling characteristics.



(a)



(b)



(c)

Fig. 5. Response surface plots for peeling effectiveness with two parameters

3.5 Numerical and Graphical Optimization of Independent Parameters

In order to find the best peeling conditions for taro, efforts were made to optimize the process parameters (rotating disc speed, peeling duration and batch load). On the basis of the optimization of process parameters (independent) was accomplished by numerical and graphical methods by setting the goals of each process parameter and response parameters using Design Expert software. Numerically, the optimum level /value for each of the process parameters were described through the desirability function technique [18]. It employs transformation of response parameters on a scale of 0 (completely undesirable) to 1 (most desirable) for desirability function analysis. The goal for each of these parameters was set in the experimental range [19] based on the requirements of the mother corm peeling process (maximum peeling efficiency with minimum material loss).

For the analysis of each of the response parameters separately, the η_p and PE were set to their possible maximum, whereas the ML was set to possible minimum. The comparative weightage of different dependent parameters was assigned in relation to other responses to obtain the desirability. The solution with maximum desirability can be considered as the optimum solution. In the present case, the first solution was considered, and the corresponding values of the process parameters for this solution were rotating disc speed of 454.94 rpm, peeling duration of 114.6 sec and batch load of 1.33 kg, respectively. These values can be considered as rotating disc speed of 455 rpm, peeling duration of 115 sec and batch load of 1.35 kg, respectively.

The optimal contour plot obtained of different responses is shown in Fig. 6. It can be further seen that the combination of process parameters, rotating disc speed, peeling duration and batch load coincided with the optimum solution generated through numeral solution. Under these optimum conditions, the desired peeling characteristics of mother corms the combination of process parameters (rotating disc speed of 455 rpm, peeling duration of 115 sec and batch load of 1.35 kg) generated the optimum condition, it will have the maximum peeling efficiency (η_p = 92.64%), peeling effectiveness (PE = 84.87%) and minimum material loss (ML = 8.21 %).

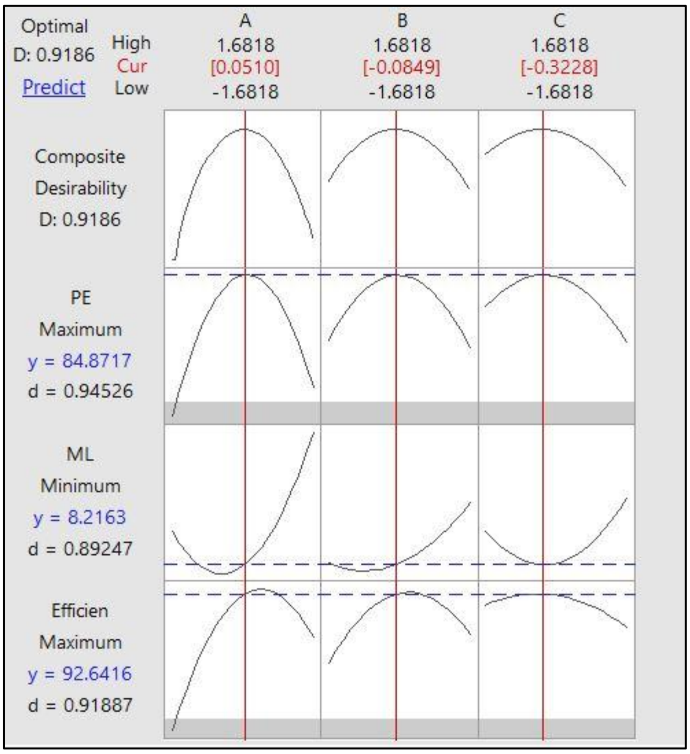


Fig. 6. Optimal plot of peeling process parameters for mother corm

3.6 Validation of the Optimum Solution

The validation of optimum process conditions for mother corm (rotating disc speed of 455 rpm, peeling duration of 115 sec and batch load of 1.35 kg) obtained through numerical and graphical techniques was used for testing the acceptability of model equations for predicting the response values. Three experiments were conducted, and average values for all the responses were calculated.

The experimental values were found to be very close to the predicted values η_p, ML and PE for mother corm were 90.54 ± 0.69 %, 8.21 ± 0.36% and 84.87 ± 0.60 %, respectively. Therefore, it could be concluded that model eqns. (6,7 and 8) are quite adequate to assess the behavior of the taro and mother corm peeling processes.

4. CONCLUSION

Peeling is a critical stage in the processing of taro corm to value-added products such as flour and starch. The optimum peeling parameters for mother corm in a commercial abrasive peeler were investigated using RSM in conjunction with CCRD to achieve optimum peeling efficiency and effectiveness with minimal material loss. In this work, a commercial tuber peeling machine was optimised for mother corm peeling. The optimized peeling conditions were found to be the rotating disc speed of 455 rpm, peeling duration of 115 sec and batch load of 1.35 kg, which yielded the peeling efficiency of 92.64 ± 0.69 %, material loss of 8.21 ± 0.36 % and peeling effectiveness of 84.87 ± 0.60 % were obtained. This study showed that mother corms and other crops of similar kind can be successfully peeled using the commercially available abrasive peeler.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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