Optimization of a de-skinning process parameters for roasted peanuts

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Abstract: Peanuts were de-skinned by abrasion provided by abrasive rolls mounted on a horizontal shaft in de-skinner machine. Responses surface methodology (RSM) and Central Composite Rotatable Design (CCRD) were used for optimization of de-skinner machine parameters for roasted peanut. The rotational speed (1000-1400 rpm) of de-skinning roller and outlet opening (4-18 mm) of de-skinning machine were taken as independent variables. The response variables were considered as a De-skinning efficiency (%), output capacity (kg h^{-1}) and specific energy consumption (kW h kg^{-1}). The regression coefficients of the linear, quadratic polynomial models for the response variables were generated and analyzed. The performance of machine was significantly affected by the moisture content of kernels and the rotational speed of the mill. The individual and interaction terms of roller speed, and outlet opening of the de-skinning machine on the de-skinning efficiency, specific energy consumption and output capacity were highly significant ($p \leq 0.01$, $p \leq 0.05$) with respective R^2 values 0.95, 0.98, 0.98. The de-skinning efficiency (90.54% ± 1.2%), capacity (44.5 ± 2.4 kg h^{-1}) and specific energy consumption (0.0314 ± 0.045 kW h kg^{-1}) were obtained for roasted peanut with optimum machine operating parameter viz. roller speed 1300-1400 rpm and outlet opening 4.6- 9.6 mm. This study will help to small scale venders to optimize the de-hulling and peeling of the cereals and oilseeds grain process.

Keywords: roasted peanut, de-skinning, specific energy consumption, de-skinning efficiency

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1 Introduction

The groundnut (*Arachis hypogeae* L.) also knows a peanut, earthnut, monkeynut and ground bean is the fourth most important source of edible vegetable oil and third most important source of vegetable protein (Singh and Singh, 1991). India is the second largest producer of groundnut in world with annual production of 5.19 lakh tonnes in the year 2018-19 (APEDA, 2019). Groundnut is valued for its protein content, having moderate biological value (Khodke et al., 2014). The edible oil, protein meal and protein isolate and flour products are widely used in India and abroad countries. The Asian and African countries mostly consumed cereal and legume products as sources of their dietary proteins to full fill the energy protein balance and the other non-indigenous products such as peanut butter, peanut curd, peanut milk, therapeutic food etc. which are also used in Asian countries (Chang et al., 2013). Peanuts contribute not only to a healthy diet but

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now are a key element in the fight against malnutrition (Beesabathuni and Natchu, 2010). The outer hulls (6%-8%) of peanut seeds have a large number of contaminating microbes and toxic chemicals such as trypsin and phytic acid etc. which can be risky for human health since they interfere with the bioavailability of micronutrients like iron, zinc, and calcium (Mensah and Tomkins, 2003). Dhanker and Chauhan (1987) conducted the test in peanuts and found that the aflatoxins on the surface produced the toxins in the food. The non-edible parts removed by using peeling and de-hulling equipment, reduced the levels of harmful contents in the foods such as glycosides in the root tubers and germinated millets (Mensah and Tomkins, 2003).

A dehuller machine in general produced four different constituents namely de-hulled seed, de-hulled broken, skins and hulls. The overall performance of the process is dependent upon the de-hulling efficiency, breakage and energy consumed to do the desired work. Tranchino et al. (1983) and Subramanian et al. (1990) analyzed the effectiveness of de-hulling as a function of operating conditions and grain characteristics. Gupta and Das (1999) reported a combination of input process variables to obtain a better dehulling performance. Ogunwole (2013) designed a de-hulling machine and tested its performance in terms of the dehulling efficiency, damage grain and energy consumption. The central composite rotatable design (CCRD) and response surface methodology (RSM) techniques were used for optimization of de-skinner machine parameters for roasted peanut (Gouveia et al., 2008). The main purpose of this study was to optimize process parameters for de-skinning machine at optimum responses values.

2 Materials and methods

2.1 Sample preparation

The fresh and matured peanut seeds were procured from the local market of Kharagpur, West Bengal, India. The peanut was manually cleaned to remove all foreign matter, broken or immature seeds. The cleaned peanuts were roasted in pilot scale roaster machine (Model: MAPL01, Miranda Automation Pvt. Ltd., Mumbai) at temperature of 160ºC and time of 25 min. The batches of roasted peanuts were stored in cool and dry place for further testing of de-skinning machine.

2.2 Experimental design and plan

In preliminary trials, the de-skinner machine was tested for de-skinning efficiency (%), specific energy consumption (kW h kg-1) and output capacity (kg h-1) of roasted de-skinned peanut (kg h^{-1}). The face central composite design (FCCD) with two independent de-skinner machine parameters viz., abrasive roll speed, and abrasive residence time (outlet opening) was used and performed by the Design Expert (version 7.1.1) software package. Experimental plan for optimization included three response variables viz., de-skinning efficiency, output capacity and specific energy consumption. The response surface methodology (RSM) was used to fit second-order polynomial model for de-skinning of roasted peanuts. The coded values of independent variables viz., x1 and x2 were converted into their real form as X1, and X2, respectively by using the Equation 1. The real and coded values of independent variables are presented in Table 1.

$$\boldsymbol{X_i} = \frac{x_i - \bar{x}_i}{\Delta x_i} \quad (1)$$

Where; X_i is the coded value of an independent variable, x_i is the real value of an independent variable, is $\bar{x}_i$ the real value of an independent variable at the central point, and Δx_i is the step change.

Table 1 Real and coded values of independent variables used in experiment

Abrasive roll speed (rpm)		Outlet opening size	
Actual (X_1)	**Coded (x_1)**	**Actual (X_2)**	**Coded (x_2)**
1000	−1	4	−1
1200	0	11	0
1400	+1	18	+1

2.3 De-skinning process

A peanut de-skinner (Model: MAPL03; M/s MAPL, Mumbai, India) fitted with four numbers (2 set) of abrasive rolls (diameter: 60 mm, length: 600 mm) was used for this purpose (Figure 1). The rotation speed of the abrasive roll was varied from 1000 to 1400 rpm using variable frequency drive mechanism. Outlet opening of de-skinned peanuts in the machine was varied from 4 to 18 mm for the output capacity of de-skinned peanuts. The blower was fitted at the bottom of the abrasive roll to collect the skins of peanut by suction of air pressure and transferred into the cyclone separator for separation of skins. The de-skinned peanuts were collected at specified time. The whole peanut (without skin) was manually separated from skins (outer hulls) and de-skinned peanuts lot. The responses (de-skinning efficiency, output capacity and specific energy consumption) were calculated.

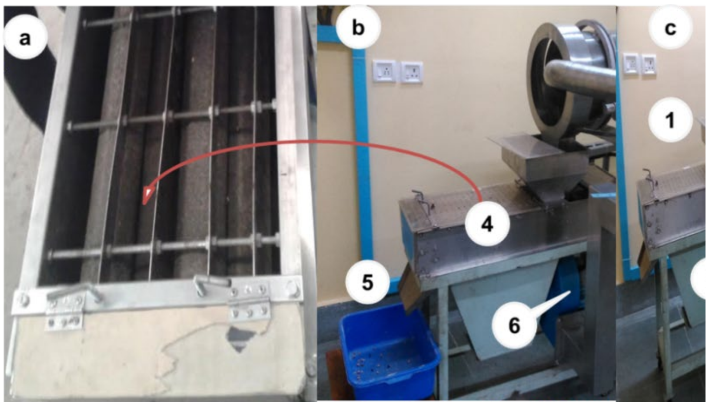

Figure 1 Schematic view of selected de-skinner: (1) Hopper, (2) Skin collection hopper, (3) Cyclone separator, (4) De-skinner rolls, (5) Split nut peanut outlet, (6) Blower

2.3.1 De-skinning efficiency

De-skinning was defined as the ratio of total weight of the roasted de-skinned split peanuts to the initial weight of the roasted peanuts (Joyner and Yadav, 2015) and calculated by Equation 2

$$D_e = \frac{W_{ts}}{W_i} \times 100 \quad (2)$$

Where; D_e is de-skinning efficiency of the machine (%), W_{ts} is total weight of the roasted de-skinned split peanuts (kg) and W_i is the initial weight of the roasted peanuts (kg).

2.3.2 Output capacity (Dhal yield)

The output capacity was defined as the yield of de-skinned split peanut as a percentage of the initial weight of roasted peanut kernels used for de-skinning (Burridge et al., 2001) and calculated by Equation 3

$$D_o = \frac{W_d}{S_t \times 3600} \quad (3)$$

Where; D_o is output capacity of the roasted de-skinned split peanuts (kg h^{-1}), W_d is mass of the output of roasted de-skinned split peanuts (kg) and S_t is duration of de-skinning process (s).

2.3.3 Specific energy consumption

Specific energy consumption (kW h kg^{-1}) was calculated by using the Equation 4 and Equation 5 which is a function of de-skinning time, current and electrical potential. The time of de-skinning was noted with a digital stopwatch. Each experiment was repeated twice. From the data recorded by the electrical clamp meter, the electrical power for three phases was calculated using the following Equation 4 (Mohd Rozalli et al., 2015).

$$P = \frac{\sqrt{3} \times V \times I \times p_f}{1000} \quad (4)$$

Where; P is the power (kW), I is the current (A), V is the electrical potential (V) and p_f is the dimensionless power factor. The power factor was considered to 0.99 during the operation. The ampere was recorded by using clamp tester during the milling operation under no load condition and feed rate (Mohd Rozalli et al., 2015). The specific energy consumption during operation was calculated using Equation 5.

$$'E = \frac{(P \times t)}{Q_d} \quad (5)$$

Where; E is the specific energy (kW h kg^{-1}), t is time in hours and Q_d is the capacity (kg).

2.4 Statistical and data analysis and optimization

Data analysis, experiment design, model equations generation and model fittings were performed by using the statistically tool package of Design Expert 8.0.7.1 software. The numerical optimization technique was used with desirability function in response surface methodology approach. The goal was maximizing the output capacity and de-skinning efficiency and minimize for specific energy consumption in order to predict the optimum process condition. Further confirmatory experiments were conducted at the optimized condition to validate the results.

3 Results and discussion

3.1 Effect of machine parameter on de-skinning efficiency and de-skinning capacity

The average responses (de-skinning efficiencies, de-skining capacity and specific energy consumption) values were obtained from the different combination of experiments are shown in Table 2. The responses were varied at different speed and outlet opening of de-skining machine. The de-skinning efficiency and deskinning capacity data of machine under different combination of machine operation parameter were analyzed by Analysis of variance (ANOVA) and the results of analysis are reported in Table 3. In this model, higher F value (57.4) suggests that the quadratic model can be successfully used to fit the experimental data at p<0.01, and p<0.05 levels. Both linear terms of speed and outlet opening have significant effect on model (p<0.01 and p<0.05). The square term of N_{RS} was significant (p<0.01) whereas outlet opening (O_{op}) was insignificant. The interaction was significant at (p<0.05) and the lack of fit were non-significant. The value of coefficient of determination (R^2=0.97) obtained for the response variable indicated that the developed model for de-skinning efficiency adequately explained 97% of the total variation, within the range of input variables studied.

Table 2 Effect of machine parameters on de- skinning efficiency (%), de-skinning capacity (kg h^{-1}), and specific energy consumption (kW h kg^{-1})

Exp. No	Independent variables: Roller speed (rpm)	Independent variables: Outlet Opening (mm)	Responses*: De-skinning Efficiency (%)	Responses*: De-skinning Capacity (kg h^{-1})	Responses*: Specific Energy Consumption (kW h kg^{-1})
1	1000 (-1)	11(0)	65.00 ± 0.23	31.0 ± 0.53	0.037 5±0.0003
2	1200 (0)	11(0)	65.01 ± 0.23	56.3 ± 0.39	0.0239 ±0.0001
3	1200 (0)	11(0)	63.24 ± 0.23	54.2 ± 0.20	0.0247 ± 0.0005
4	1200 (0)	18(+1)	58.19 ± 0.13	83.2 ± 0.89	0.0124 ± 0.0001
5	1000(-1)	4(-1)	71.03 ± 0.16	23.2 ± 0.39	0.0698 ± 0.0006
6	1400 (+1)	18(+1)	66.12 ± 0.13	94.8 ± 0.27	0.0141 ±0.0009
7	1000(-1)	18(+1)	59.26 ± 0.10	56.8 ± 0.33	0.0125 ± 0.0003
8	1200 (0)	4(-1)	78.34 ± 0.07	32.6 ± 0.24	0.0509 ± 0.0006
9	1200 (0)	11(0)	64.24 ± 0.18	52.8 ± 0.45	0.0231 ± 0.0007
10	1400 (+1)	11(0)	80.11 ± 0.10	66.0 ± 0.25	0.0208 ± 0.0001
11	1200 (0)	11(0)	62.34 ± 0.15	53.1 ± 0.45	0.0239 ± 0.0006
12	1400 (+1)	4(-1)	91.23 ± 0.17	44.8± 0.15	0.0323 ± 0.0003
13	1200 (0)	11(0)	63.02 ± 0.14	55.6 ± 0.20	0.0219 ± 0.0004

Note: * Experimental values are reported as mean ± standard deviation (SD) (n=3)

Table 3 Model coefficients and ANOVA data describing for the de-skinning efficiency (P_{EF}), de-skinning capacity (P_{OC}) and specific energy consumption (S_{EC})

Source	P_{EF}	P_{OC}	S_{EC}
Model	+241.51**	-188.10**	+0.32**
N_{RS}	-0.32**	+0.31**	-3.11189E-004**
O_{op}	+0.55**	-2.49**	-0.013**
$N_{RS} \times O_{op}$	$-2.38\times10^{-3*}$	$+2.90\times10^{-3}$*	$+6.98\times10^{-6}$**
$(N_{RS})^2$	$+1.60\times10^{-4}$**	-1.13×10^{-4}*	$+7.93\times10^{-8}$*
$(O_{op})^2$	$+0.043^{ns}$	+0.09*	$+1.15\times10^{-4}$**
p model	<0.001	<0.001	<0.001
F value	57.40	130.42	191.67
Lack of Fit	Ns	ns	Ns
Coefficient of variation (CV), %	2.82	4.92	6.45
Adequate Precision Ratio (APR)	27.37	42.04	48.17
Pred. R^2	0.85	0.91	0.95
Adj. R^2	0.95	0.98	0.98

Note: ** p<0.01, * p<0.05, ns - Non–significant N_{RS}: Roller speed, O_{op}: outlet opening

From the Figure 2, it is observed that the de-skinning efficiency increased with the increase in roller speed but decreased with the outlet opening of the machine. This might be due to the fact that lower outlet opening extends the residence time. The higher roller speed boosts up the shear impact forces that causes an increase in the de-skinning efficiency. At higher outlet size of peanut, low de-skinning efficiency notices this might be due to the lower contact of roasted peanuts which was not sufficient or enough to generate centrifugal force and could not rupture the skin during the de-skinning process and vice versa. The roller speed has significant effect on deskinning efficiency of roasted peanuts which supports the study of Ndukwu and Asoegwu (2010) and Sobowale et al. (2015).

The ANOVA data of de-skinning capacity is presented in Table 3. The higher F value (130.42) of model suggests that the quadratic model can be successfully fitted to the experimental data (p <0.01). The linear and quadratic terms of the roller speed have a significant effect on the de-skinning capacity (kg h^{-1}) of the de-skinning machine. The effect of interaction term of independent variables was also found significant at 5% level; the lack of fit was not significant. The similar study was reported by Olotu et al. (2013) in the dehulling of cowpea seeds and author observed the dehulling capacity was varied with speed of dehulling machine.

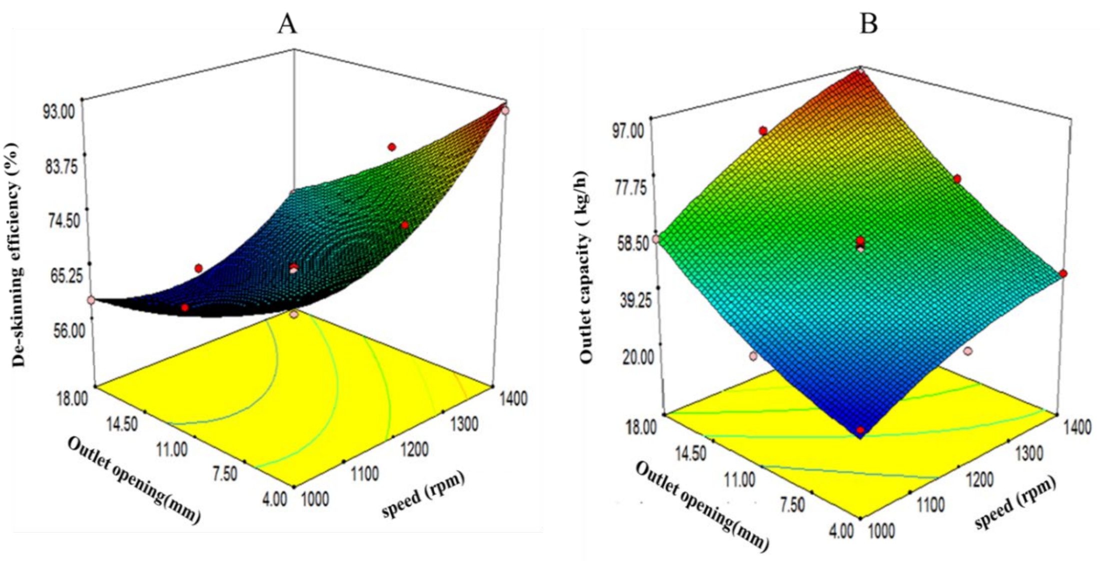

Figure 2 Response surface graph for (A) de-skinning efficiency and (B) de-skinning capacity of roasted peanut with varying roller speed and outlet opening

The predicted R^2 (0.91) for this model was also in reasonable agreement with adjusted R^2 (0.98). The CV and APR for the developed model were 4.92% and 42.04, respectively indicating the adequate precision of the model. The de-skinning capacity was estimated as function of roller speed and outlet opening of the machine. Figure 2B is shown the de-skinning capacity (kg h^{-1}) of the roasted peanut and it is noticed that the de-skinning capacity increased with increasing of outlet opening and roller speed of machine but simultaneously reduce the de-skinning efficiency of roasted peanut at higher outlet opening and roller speed. The current study supports the finding by the Fadeyibi and Faith Ajao (2020).

3.2 Effect of machine parameter on specific energy consumption of roasted peanut

The ANOVA data of specific energy consumption (SEC) results are presented in Table 3. The comparatively very high model F value (191.67) suggests that the developed quadratic model can be successfully used to fit the experimental data (p<0.001). Both the linear terms N_{RS} and O_{op} have high influence on specific energy consumption (p<0.001). The quadratic terms of both parameters affect (p<0.05) the specific energy consumption during the de-skinning of roasted peanut. The lack of fit was observed to be non- significant at 5% level. The predicted R^2 (0.95) for this model was also in reasonable agreement with adjusted R^2 (0.98). The CV and APR for the developed model were 6.45% and 48.17%, respectively, indicating the adequate precision of the model. It can be seen in the Figure 3 that the specific energy consumption increased gradually with the decrease in the outlet opening of the de-skinning machine.

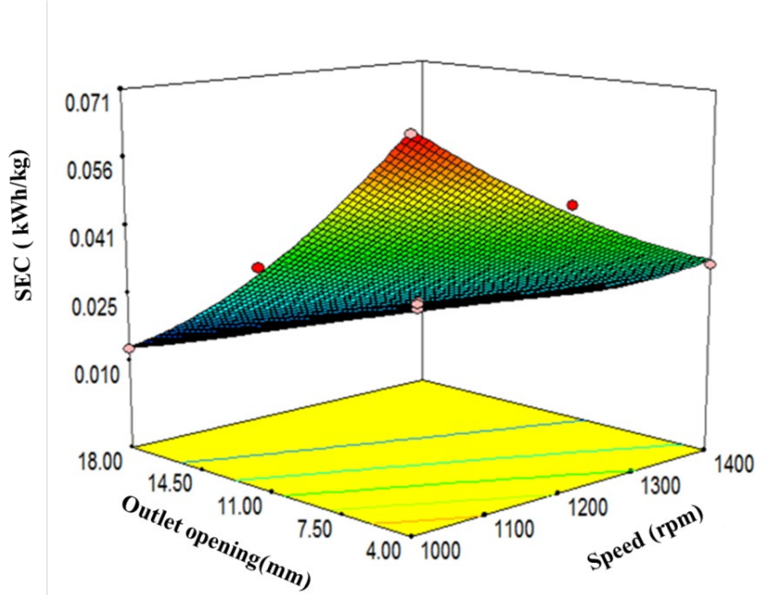

Figure 3 Response surface for specific energy consumption of roasted peanut with varying roller speed and outlet opening of de-skinning machine

3.3 Optimization and validation

The regression model equations are allowed to the prediction of the effects of the independent variables on the de-skinning efficiency, output capacity and specific energy consumption, and design-expert (version 7.1.1) software was performed to optimize the input variables. The de-skinning efficiency and capacity were set maximize and minimize for specific energy consumption while other parameters were kept in range during optimization of the de-skinning process conditions.

Table 4 Optimization criteria, optimum conditions, predicted, and experimental values for different process variables and responses for de-skinning of roasted peanut.

Process variables/ Response	Goal	Predicted	Experimental
Speed of roll (rpm)	In Range	1400	1400
Outlet opening (mm)	In Range	4.61	5
De-skinning efficiency (%)	Maximize	91.23	90.54 ± 1.2*
De-skinning capacity (kg h^{-1})	In Range	45.24	44.5± 2.4*
Specific energy consumption (kW h kg^{-1})	Minimize	0.0317	0.0314 ± 0.045*

Note: * values are reported as mean ± standard deviations

The predicted and experimental values of responses obtained as per the desired criteria and optimized solution are shown in the Table 4. Experiments were conducted on optimized machine parameters for the validation of the model. From the Table 4, the experimental value of de-skinning efficiency, capacity and specific energy consumption were closely related and statistically insignificant, with the predicted values, which is showing the adequacy of developed model. The process parameters conditions obtained by RSM were accurate, reliable, and also had a practical value (Xu et al., 2013).

4 Conclusions

The aim of this present study was to determine the optimum process parameters of de-skinning machine at minimum degradation in the quality of roasted de-skinned peanut. In this investigation, the levels of independent variables (abrasive roll speed and outlet opening of the de-skinner machine) were optimized to yield maximum of de-skinning efficiency, deskinning capacity and minimum specific energy consumption. Response models for the predicting of de-skinning characteristics of roasted peanut were developed as functions of outlet opening and abrasive roller speed. The individual and interaction terms of roller speed, and outlet opening of the de-skinning machine on the de-skinning efficiency, specific energy consumption and output capacity were found highly significant ($p \leq 0.01$, $p \leq 0.05$). The de-skinning efficiency (90.54% ± 1.2%), capacity (44.5 ± 2.4 kg h^{-1}) and specific energy consumption (0.0314 ± 0.045 kW h kg^{-1}) were obtained for roasted peanut with optimum machine operating parameter viz. roller speed 1300-1400 rpm and outlet opening 4.6- 9.6 mm.

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