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Optimization of Kabuli chickpea dehulling process

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Abstract

Dehulling of chickpea is an important process for preparing value-added products. To improve the dehulling characteristics, a tangential abrasive dehulling device (TADD) was used to investigate the effect of the rotational speed and grit size of abrasive disk, microwave exposure and retention time on the dehulling behavior of chickpea grain. Response surface methodology (RSM) based on a four-factor, five-level and central composite design was employed to study the effect of the independent variables and optimize processing conditions. In order to obtain higher dehulling efficiency accompanying with decreasing dehulling loss optimization process was done. The best condition of dehulling was obtained with rotational speed of 790.44rpm, microwave exposure time of 98s, retention time of 120s and grit size of 50 so that the dehulling efficiency of 86.02% and dehulling loss of 2.6% were recorded.

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Introduction

The nutritional importance of pulses as an economic source of proteins, carbohydrates, minerals, and vitamins has been recognized throughout the world (Chavan *et al.*, 1987). Chickpea is the second most important pulse crop in the world which is grown in at least 33 countries located in South and West Asia, North and East Africa, southern Europe, North and South America, and Australia (Singh, 1997). It is a good source of carbohydrates and protein, and its protein quality is considered to be better than that of other pulses. Chickpea is also a good source of important vitamins such as riboflavin, niacin, thiamin, folate and the vitamin A precursor b-carotene (Jukanti *et al.*, 2012). The shape, size, and color of chickpea seeds vary according to its cultivars. Based on seed color and geographical distribution, chickpeas are generally grouped into two types: Kabuli (Mediterranean and Middle Eastern origin), and Desi (Indian origin). The former type is large, smooth coated, rams-head shaped and beige colored, whereas the latter one is small, angular, wrinkled and dark colored (Chavan *et al.*, 1987; Miao *et al.*, 2009).

Chickpea grain undergoes various processing operations such as: dehulling, splitting, grinding, puffing, parching and toasting prior to milling and its usage in a variety of food preparations, resulting in improvements in appearance, texture, culinary properties and palatability and reduced cooking time. Dehulled seeds are easily digested and efficiently used by the body (Kurien, 1987). Pulse decortication and splitting is an important agro-based industry that has been developed through trial-and-error approach. This is might be the reason for the diversity of methods and machinery adopted by pulse processors in different parts of the world. The effectiveness of dehulling depends on the grain properties and the type of dehuller (Sokhansanj and Patil, 2003). According to Chavan *et al.* (1987), chickpea dehulling behavior is affected by the content and amount of hull, the chemical nature and hydration level of gums exiting between the cotyledon and the hull, shape, size, grading, moisture content and hardness of the grain. Dehulling time is an important parameter, which affects dehulling efficiency and dehulling loss.

The economy of the dehulling process for grains depends on the efficient removal of the hull without excessive breakage and loss of the cotyledon during dehulling. Previous studies by abrasive devices have shown that dehulling efficiency can be optimized by effective determination of sample size, feed rate, rotational speed, diameter, clearance, grit size, and the retention time for each run(Erskine *et al.*, 1991; George *et al.*, 2014). The maximum dehulling efficiency of 73.53% was found with 1400rpm roller speed and 60kg/h feed rate for pigeon pea dehulling (Mathukia *et al.*, 2014). The dehulling performance of flaxseed was favorable at lower moisture content (1.9% wb and 4.5% wb) for 40 sec residence time and 2000rpm of abrasive disc (rotor) of the polisher (Barnwal *et al.*, 2010). The roller peripheral speed of 10m/s, 0.3mm emery grit size and feed rate 101.60kg/h were found optimal for pigeon pea, chickpea and green gram dehulling (Mangaraj and Singh, 2011) using CIAE dal mill.

Grain conditioning prior to dehulling and milling is done to break the bonding between the hull and the cotyledon. Response surface methodology has been successfully applied for optimizing conditions in food research (Akinoso *et al.*, 2011; Baş and Boyacı, 2007; Chakraborty *et al.*, 2007; de Figueiredo *et al.*, 2013; Goyal *et al.*, 2008; Goyal *et al.*, 2009; Mrad *et al.*, 2015; Wang, 2005). The RSM,as a most popular optimization method (Baş and Boyacı, 2007) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes (Myers *et al.*, 2009). The dehulling parameters of black gram were significantly improved through continuous hydrothermal treatment using RSM (Jerish Joyner and Yadav, 2015). The maximum dehulling efficiency for pigeon pea was obtained at 10.1% moisture content (db), 12.3s dehulling time and 03% mustered oil treatment (Goyal *et al.*, 2008).

The objective of the present study was to optimize the rotational speed and grit size of abrasive disk, microwave exposure and retention time using RSM to maximize efficiency and to minimize loss during dehulling process.

Materials and methods

Experiment material

Kabuli chickpea grains were obtained from the local market (Swift current, SK, CA). After cleaning, undeveloped, damaged and broken chickpea kernels as well as non-grain materials were removed from the samples prior to grading. Kernels were conditioned using the traditional method used in Mama an, Iran, which is similar to Sari Leblebi production method used in Turkey (Coşkuner and Karababa, 2004), as presented in Fig 1. Following the cleaning, samples were tempered (preheated and roasted), moistened. Stored, and finally, dehulled. Tempering process included preheating and resting stages. First and second preheating were performed at 110-120°C for approximately 20 and 8 min, respectively. In the first and second tempering stages, preheating of chickpeas were followed by resting in a hemp sack for 2 days, and in a plastic sack for 10 days, respectively.

After tempering process, distilled water were added by spraying to increase the moisture content up to 14-15%. Then, they were stored in airtight plastic bags for 24 hours.

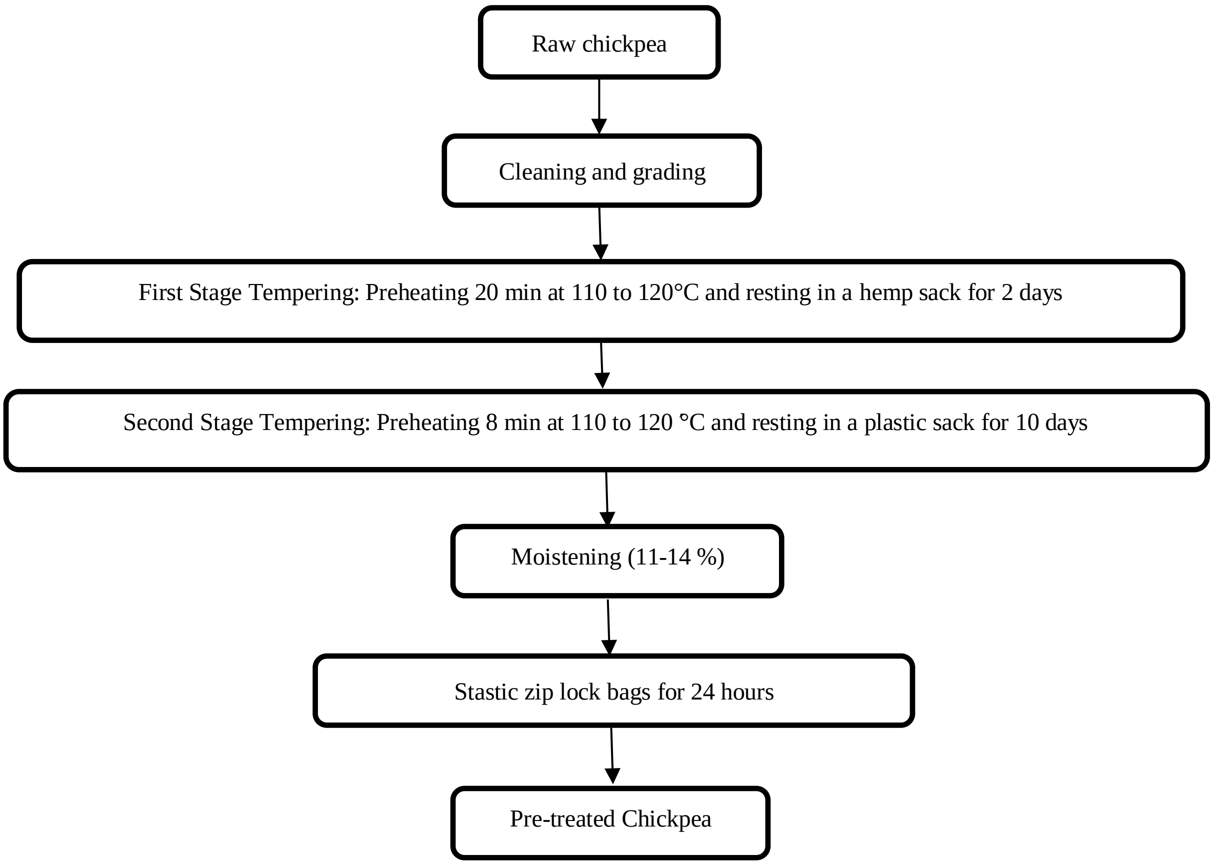

Fig. 1. Sample preparation scheme

Microwave oven

Prior to dehulling, a microwave oven (Panasonic NN-C980W, ON, Canada) having the maximum output power of 1100 W at 2450 MHz was used to conduct the experiments. For each experiment, a total weight of 400g of the pre-treated grains were poured in eight glass dishes and left in the microwave oven. Five different exposure times were applied ranging from 30 to150s at an interval of 30s.

Dehulling

Dehulling characteristics were investigated with the Tangential Abrasive Dehulling Device (Model 4E-230 TADD, Venables Machine Works Ltd., Saskatoon, SK, Canada), and it's electric motor was replaced with 3 phase inverter driven electric motor to achieve different rotational speeds. Five different grit size sandpapers were used as abrasive surfaces.

Sandpapers were attached to an aluminum disk using adhesive. For each run, weighed samples of grain were placed in the cup, the cover plate fastened in position, and the abrasive disk was rotated under the cups at certain speeds and retention times. The abraded samples were then removed from the sample cups with the vacuum sample collector described by Oomah *et al.* (1981), while the mixture of hull and fines were manually separated using a 20 mesh sieve size mounted over a 100 mesh sieve size. After dehulling, the different fractions of samples were collected and graded into three groups of fully dehulled, broken, and powder, and weighed separately for further analysis. Dehulling efficiency (DE) % was calculated using the following formula (Goyal *et al.*, 2008).

$$DE = (1 - \frac{W_h}{W_t})(\frac{W_p}{W_p + W_r + W_o}) * 100 \quad (1)$$

W_h : weight of undehulled grain in g,

W_t : total weight of grain used for dehulling in g,

W_p : weight of finished product in g,

W_r : weight of broken grains in g, and

W_o : weight of powder in g.

Similarly, the percentage of dehulling loss (DL) in terms of broken and powdered grains was calculated using the following formula:

$$DL = (\frac{W_r + W_o}{W_t}) * 100 \quad (2)$$

Where:

W_t : total weight of grain used for dehulling, g,

W_o :weight of powder obtained, g and

W_r : weight of broken, g

Experimental design

Central composite rotatable design with four independent machine parameters i.e. rotational speed, grit size of abrasive disk, microwave exposure, and retention time were used to optimize the process parameters for maximum dehulling efficiency with minimum Dehulling loss (Table 1).

It was assumed that independent variables would affect the responses. The responses in terms of dehulling efficiency DE and dehulling loss DL were assumed to describe the relationships between responses and factors as follows:

DE= $f(x_1, x_2, x_3, x_4)$ (3)

DL= $f(x_1, x_2, x_3, x_4)$ (4)

Experimental data were fitted to obtain a second-order polynomial equation:

$$DE = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{4} \beta_{ii} x_i^2 + \sum \sum_{i<j=2}^{4} \beta_{ij} x_i x_j \quad (5)$$

$$DL = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{4} \beta_{ii} x_i^2 + \sum \sum_{i<j=2}^{4} \beta_{ij} x_i x_j \quad (6)$$

Where β_0, β_i, β_{ii} and β_{ij} are coefficients for intercept, linearity, quadraticity, and interaction, respectively. x_i and x_j are coded independent variables.

In this study, the optimization was performed in Design Expert 8 software, which gives optimum conditions based on prefixed conditions. Dehulling experiments were carried out at optimum conditions obtained from software to verify the results and were replicated thrice and tested for any significant deviations from the predicted values.

Results and discussion

The experimental results in terms of dehulling efficiency and dehulling loss are shown in Table 2. Sequential model sum of squares suggested the quadratic effect of pre-treatments.

Table 1. Independent variables and their coded levels used for optimization of chickpea dehulling.

Independent variable		Coded level				
		-α	-1	0	1	+α
Rotational speed	x_1	250	500	750	1000	1250
Microwave exposure	x_2	30	60	90	120	150
Retention time	x_3	60	90	120	150	180
Grit size	x_4	20	30	40	50	60

Response surfaces were obtained using α = 2.

Dehulling efficiency

Tables 3 shows the analysis of variance (ANOVA) of the regression parameters of the predicted response surface quadratic model. The obtained model showed high correlation coefficient ($R^2 > 0.88$). The high value of R^2 suggests that the second-order model is adequate; however, a significant lack of fit suggests a need for the transformation of the model.

As seen in Table 3, the effects of all studied parameters (except microwave exposure time) on dehulling efficiency were significant (P<0.05). In addition, interactions of rotational speed and retention time, and rotational speed and grit size were significant (P<0.05). The regression equation obtained for the model of the second degree in terms of coded factors is given in the following equation:

$$DE = 83.31 + 9.90\,x_1 + 3.00\,x_2 + 6.80\,x_3 + 6.58\,x_4 + 1.95\,x_1x_2 - 6.94\,x_1x_3 + 12.80\,x_1x_4 + 0.40\,x_2x_3 - 0.25x_2\,x_4 + 4.60\,x_3x_4 - 13.85x_1^2 - 6.41\,x_2^2 - 7.56\,x_3^2 - 7.83\,x_4^2 \quad (7)$$

$R^2=0.89$

Table 2. Observed response values with different combinations of Rotational speed (x_1), Microwave exposure (x_2), retention time (x_3) and grit size (x_4).

run	x_1	x_2	x_3	x_4	DE	DL
1	-1	-1	1	-1	48.92	41.98
2	0	-2	0	0	58.04	33.53
3	-1	-1	-1	1	12.73	7.49
4	1	-1	-1	1	58.22	28.06
5	-1	-1	1	1	46.80	3.66
6	1	1	1	-1	39.80	58.14
7	-1	1	-1	-1	51.23	24.08
8	0	0	0	0	85.86	7.39
9	0	0	0	2	85.51	12.86
10	-1	1	1	-1	61.66	30.00
11	0	0	0	0	86.02	6.88
12	2	0	0	0	58.24	39.34
13	0	0	-2	0	38.34	17.04
14	-2	0	0	0	0.00	0.00
15	0	0	0	0	79.12	13.12
16	0	0	0	-2	20.87	11.74
17	1	1	1	1	77.16	21.35
18	1	-1	1	-1	37.08	58.89
19	0	0	0	0	82.12	8.14
20	1	-1	-1	-1	36.73	59.32
21	-1	-1	-1	-1	40.10	28.47
22	-1	1	-1	1	1.24	2.07
23	1	1	-1	-1	46.48	51.02
24	-1	1	1	1	53.14	18.44
25	0	0	0	0	84.55	8.33
26	0	0	2	0	70.24	27.64
27	1	-1	1	1	61.49	35.33
28	0	0	0	0	82.17	6.96
29	1	1	-1	1	79.96	8.30
30	0	2	0	0	59.76	19.85

The sign and magnitude of the coefficients indicate the effect of the variable on the response. A negative coefficient means a decrease in response when the level of the variable is increased, whereas a positive coefficient indicates an increase in the response.

A significant interaction suggests that the level of one of the interactive variables may increase while that of the other may decrease for a constant value of the response (Montgomery, 2008).

Table 3. Analysis of variance and regression coefficients of the second-order polynomial model for Dehulling efficiency.

Source	Sum of Squares	DF	Mean Square	FValue	p-value
Model	15689	14	1120.64	8.34	0.0001
Rotational speed, x_1	2351.82	1	2351.82	17.5	0.0008
Microwave exposure, x_2	216.23	1	216.23	1.61	0.224
Retention time, x_3	1109.2	1	1109.2	8.25	0.0116
Grit size, x_4	1040.41	1	1040.41	7.74	0.0139
$x_1 x_2$	60.68	1	60.68	0.45	0.5119
$x_1 x_3$	771.19	1	771.19	5.74	0.0301
$x_1 x_4$	2619.94	1	2619.94	19.49	0.0005
$x_2 x_3$	2.51	1	2.51	0.019	0.8931
$x_2 x_4$	1.04	1	1.04	7.74E-03	0.9311
$x_3 x_4$	337.84	1	337.84	2.51	0.1337
x_1^2	5262.52	1	5262.52	39.16	< 0.0001
x_2^2	1125.74	1	1125.74	8.38	0.0111
x_3^2	1567.21	1	1567.21	11.66	0.0038
x_4^2	1683.37	1	1683.37	12.53	0.003
Residual	2016.01	15	134.4		
Lack of Fit	1980.35	10	198.03	27.77	0.0009
Pure Error	35.66	5	7.13		
Correlation Total	17705	29			

Response surface plots are presented in Fig 2. It was observed that at fixed value of microwave expouse time 90s, dehulling efficiency gradually increased to 85% with rotational speed up to 820 rpm at retention time of 120s and Grit size of 40 and reduced thereafter.The reduction observed in DE for rotational speeds higher than 820 rpm might be resulted in morebroken and powder formationdue to higher speed. This was in agreement with results by Mangaraj and Singh (2011) saying that at fixed value of emery grit size (2.21 mm), the milling efficiency of pigeon pea gradually increased with roller peripheral speed up to 11.25m/s and reduced thereafter up to 12.03m/s. The main effect of microwave expouse time on dehulling efficiency was not significant (P>0.05). Generally, dehulling efficency increased with microwave expouse time up to 100s. Joyner and Yadav (2015) reported that the dehulling yield increased by increasing the microwave power level and exposure time. They found that the dehulling yield decreased when exposed to microwave for more than 120 s At 810 W. Fig. 2. shows that at fixed value of microwave exposure time and grit size, at rotation speeds of 500 to 1000rpm, increasingretention time from 90 to 150s, resulted in sharp increase in dehulling efficiency from 68.95% to 84.75% and then gradual decreaseto 82.55%.

Similar results were also obtained by Goyal *et al.* (2008) for pigeon pea. The predicted dehulling efficiency increased sharply with increasing rotational speed up to 955rpm for higher grit size (50 ≤ grit size), whereas DE increased gradually with increasing rotational speed up to 730rpm for lower grit size (30 ≥ grit size) and then decreased. Mangaraj and Singh (2011) showed that at fixed value of emery grit size (2.21mm), the milling efficiency of chickpea was gradually increased with roller speed from 8.91 to 12.03m/s and at feed rate of 88.11kg/h where as it decreased with revolving speed at the feed rate of l11.89 kg/h. Generally, the optimum grit size range of abrasive wheel was 40 to 50 (keeping rotational speed at 750 rpm, microwave exposure time at 90s and retention time at 120s).

George *et al.* (2014) Showed that the optimal results in the TADD mill were obtained with 200g sample size, 900 rpm, 50 and 80 grit sizes, and 180s and 240s retention times for wheat debranning. Similar reported results shows that the grit size of the grinding surface affect the dehuller performance (Oomah *et al.*, 1981).

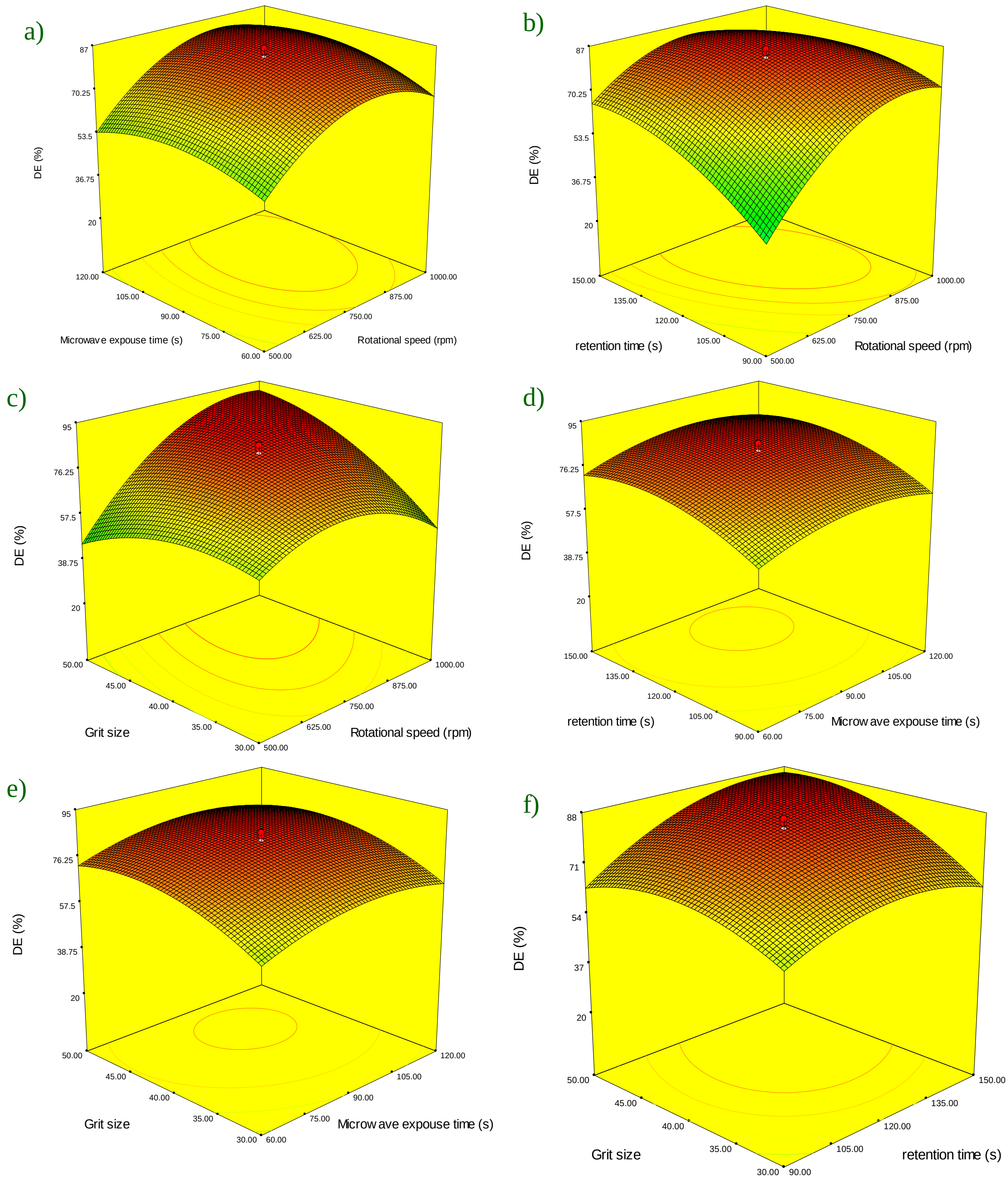

Fig. 2. Response surface plots for DL as a function of rotational speed (rpm) and grit size of abrasive disk, microwave exposure and retention time (s) keeping the third and fourth variable fixed at a) retention time-120 s and Grit size-40, b) microwave exposure time- 90 s and Grit size-40 c) microwave exposure time-90s and retention time 120s, d) rotational speed-750 rpm and Grit size-40, e) rotational speed-750 rpm and retention time-120s and f) rotational speed-750 and microwave exposure time- 90s.

Dehulling loss

It was observed from ANOVA (Table 4) that Microwave exposure and retention time are not significantly affecting the DL of chickpea, whereas rotational speed and grit size of abrasive disk arethe most significant ($p \leq 0.01$) parameters that affecting the dehulling losses of chickpea. However, interactions of these factors were non-significant.

The regression equation obtained for the model of the second degree in terms of coded factors is in the form of:

$$DL = 8.47 + 10.12\,x_1 - 3.22\,x_2 + 3.34\,x_3 - 9.37\,x_4 - 2.24\,x_1x_2 - 0.31\,x_1x_3 - 2.59\,x_1x_4 + 1.62\,x_2x_3 + 0.065x_2\,x_4 + 0.42\,x_3x_4 + 4.39x_1^2 + 6.14\,x_2^2 + 5.06\,x_3^2 + 2.55\,x_4^2 \quad (8)$$

$R^2 = 0.79$

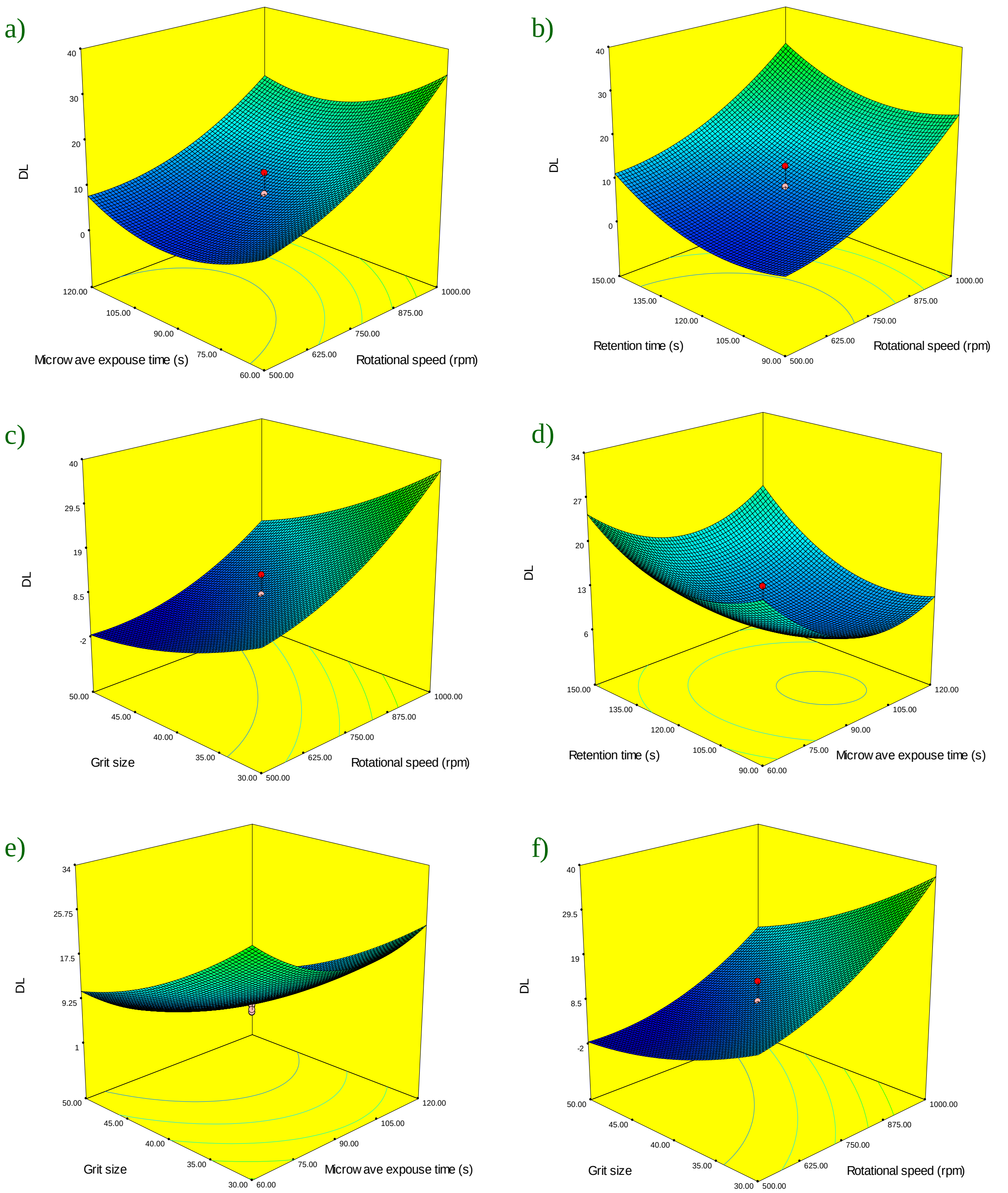

Fig. 3. Response surface plots for DL as a function of rotational speed (rpm) and grit size of abrasive disk, microwave exposure and retention time (s) keeping the third and fourth variable fixed at a) retention time-120 s and Grit size-40, b) microwave exposure time- 90 s and Grit size-40 c) microwave exposure time-90s and retention time 120s, d) rotational speed-750 rpm and Grit size-40, e) rotational speed-750 rpm and retention time-120s and f) rotational speed-750 and microwave exposure time- 90s.

Table 4. Analysis of variance and regression coefficients of the second-order polynomial model for Dehulling loss.

Source	Sum of Squares	DF	Mean Square	FV alue	p-value
Model	7114.84	14	508.20	3.97	0.0060
Rotational speed, x_1	2458.39	1	2458.39	19.20	0.0005
Microwave exposure, x_2	248.10	1	248.10	1.94	0.1842
Retention time, x_3	267.83	1	267.83	2.09	0.1686
Grit size, x_4	2108.58	1	2108.58	16.47	0.0010
$x_1 x_2$	80.04	1	80.04	0.63	0.4415
$x_1 x_3$	1.54	1	1.54	0.012	0.9141
$x_1 x_4$	107.41	1	107.41	0.84	0.3742
$x_2 x_3$	42.04	1	42.04	0.33	0.5751
$x_2 x_4$	0.068	1	0.068	5.331E-004	0.9819
$x_3 x_4$	2.84	1	2.84	0.022	0.8835
x_1^2	528.61	1	528.61	4.13	0.0603
x_2^2	1035.59	1	1035.59	8.09	0.0123
x_3^2	701.46	1	701.46	5.48	0.0335
x_4^2	177.84	1	177.84	1.39	0.2569
Residual	1920.36	15	128.02		
Lack of Fit	1892.63	10	189.26	34.13	0.0006
Pure Error	27.73	5	5.55		
Correlation Total	9035.20	29			

Response surface plots are presented in Fig 3. It was observed that at fixed value of retention time and grit size, the increase in rotational speed increases dehulling loss. Increasing abrasive disk speed caused more mechanical friction between the seed and abrasive disk, resulting in more powdered and broken samples during dehulling process.

Similar results were also observed by Wang (2005) for lentil. The results from Fig 3 demonstrate that dehulling loss decreases with increasing the grit size of abrasive disk. The decreasing trend could be attributed to the smooth surface of abrasive disk using higher grit size. The increase in dehulling time, although non-significant, increases dehulling losses, which is expected as grains are subject to more abrasion. The results are in agreement with the results reported by Goyal *et al.* (2008) for pigeon pea.

Optimization of experimental conditions

Optimum parameter levels for dehulling of chickpea were defined as those yielding maximum DE and minimum DL. The rotational speed of 790.44rpm, microwave exposure time of 98 s, retention time of 120 s and grit size of 50 were found optimal for dehulling of chickpea. At this optimized condition, the dehulling efficiency and dehulling losses were 86.02% and 2.6%, respectively. In order to verify the findings, the experiments were conducted in triplicate at optimal conditions. The average dehulling efficiency was observed to be 84.68% and dehulling losses was 3.17%, which confirms the optimum conditions.

Conclusion

The effect of rotational speed and grit size of abrasive disk, microwave exposure and retention time on dehulling characteristics of chickpea were studied and the optimum dehulling conditions were established using response surface methodology. It was found that rotational speed and grit size of abrasive disk and retention time play an important role in the dehulling performance. The rotational speed of 790.44rpm, microwave exposure time of 98s, retention time of 120s and grit size of 50were identified as optimal conditions. The optimum dehulling parameters obtained from the experiments can be used to design the dehulling device of chickpea.

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