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Response Surface Methodology to Optimize Process Parameters for Dehulling of Oats

Gagandeep Kaur, Harpreet Singh, Chavan Prasad

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ABSTRACT

Background: Oats provide a tough challenge to miller, consists of rigid outer covering called hull that comprises 30-35% of the weight of the oat grain. Hull composed of cellulose, hemi-cellulose and lignin which are inedible and not digested by humans and should be separated from oats. The study would enhance the utilization of this nutritional cereal to daily diets, as the processing of oats has not yet been exploited much at rural level in India.

Methods: The present investigation was aimed at optimizing the dehulling process to enhance recovery of oat groats. The best combination of dehulling parameters was obtained with response surface methodology (RSM) using Box-Behnken design. The independent process variables for dehulling of oats were moisture content (8-14%), feed rate (6-12 kg/h) and number of passes (2-4).

Result: Seventeen experimental runs in triplicate were conducted to obtain optimal condition moisture content: 10.62% (wb), feed rate: 7.57 kg/h and repetitive passes: 4 with dehulling efficiency of 65.79%, groat recovery 47.16% and broken percent 14.42% respectively. An analysis of variance (ANNOVA) revealed that the process variables, dehulling efficiency, groat recovery and broken percent decreased significantly ($p<0.05$) with the increase in moisture content, feed rate and number of passes respectively.

Key words: Dehulling, Oat groats, Optimization, Response surface methodology.

INTRODUCTION

Oat (*Avena sativa* L.) ranks 6th in world cereal production following by wheat, maize, rice, barley and sorghum. Oats have attracted much attention in recent years due to its nutritional and therapeutic properties and is best known for its quality protein, unsaturated fatty acids, minerals and vitamins, phoenolic compounds and dietary fiber content along with cholesterol plummeting abilities (Gangopadhyay *et al*. 2015; Smulders *et al.* 2018). There has been an increase in use of oat for human food in recent years due to its high nutritional value. About 6% of oat grains are used for human nutrition (Gilissen *et al.* 2014; Norja and Lehtinen, 2008). Oat accumulates 13.6% protein, 7.6% fat, 1.8% minerals, 3.5% fiber, 62.8% carbohydrates, 4 g beta glucan, 50 mg phosphorus, 3.8 mg iron and it provides 374 kcal energy per 100 g (Gopalan *et al.* 2007). Oat flour is used for the preparation of the bread (Majzoobi *et al*. 2015), biscuit (McMinn and Magee 2007) and noodles (Aydin and Gocmen 2011).

Like many other cereal grains, oat consists an outer portion *i.e.* hull, designed to protect the kernel from the harsh environment. Oat kernel with hull is largely non-digestible and thus must be utilized in milled form to convert it to food and reap its nutritional benefits. Milling is made up of several steps, the most important being dehulling to expose the digestible groat and cutting, rolling or grinding to convert the groat into a product that can be used as a oatmeal or ready to eat breakfast cereals or food ingredient in breads, biscuits *etc*. Oat dehulling can be achieved by a number of methods such as hand dehulling, impact dehulling, stone dehulling and compressed air dehulling (Doehlert and McMullen, 2001). These different methods show variation in efficiencies and groat recovery depends upon the dehulling conditions. The mechanical methods provide favourable results but show lower groat recovery and efficiency as compared to hand dehulling method.

Impact hulling is widely used industrial methods for removing the resilient, inedible hulls that covers the groat (Deane and Commers, 1986; Ganssmann and Vorwerck, 1995). Groat recovery is highly influenced by moisture content (Kaur *et al*. 2014). Groat recovery decreases as moisture content increased upto 15%, but increases up to 30% moisture content and groat breakage decreases as moisture increases (Doehlert and McMullen, 2001). Fluctuations can be seen in results obtained at different feed rates. The optimization of dehulling process would be critical for solutions of the problems of lower efficiency and higher broken content.

Oats provide a tough challenge to miller, consists of rigid outer covering called hull that comprises 30-35% of the weight of the oat grain (Butt *et al*. 2008). Hull composed

Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana-141 004, Punjab, India.

Corresponding Author: Gagandeep Kaur, Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana-141 004, Punjab, India. Email: gagandeep@pau.edu

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of cellulose, hemi-cellulose and lignin which are inedible and not digested by humans and should be separated from oats (Peltonen-Sainio *et al*. 2004). The current research was undertaken to study the influence of process parameters on groat recovery, dehulling efficiency and broken percent. Information gathered from the study would enhance the utilization of this nutritional cereal to daily diets, as the processing of oats has not yet been exploited much at rural level in India.

MATERIALS AND METHODS

The present research was conducted in April 2018 to September 2018 at Department of Processing and Food Engineering of College of Agricultural Engineering and Technology, Punjab Agricultural University, Ludhiana, India.

Sample preparation

Oat grains of variety (OL-09) were procured from Punjab Agricultural University Ludhiana and stored at ambient conditions till experiment was started. The initial moisture content of cleaned grains was measured by standard hot air oven method (AACC, 2000). The desired moisture content selected for study (8 to 14% w.b.) was obtained by drying the grains in a tray dryer at 40-45°C or by spraying with pre-calculated amounts of distilled water (Balasubramanian, 2001).

Experimental design

A three level three-factor Box-Behnken design was used for investigating the effect of independent variables. The independent variables and their levels for study were chosen on the basis of preliminary trial results (Erbay, 2008). The process variables included were moisture content (8 to 14 % w. b.), feed rate (6 to 12 kg/h) and number of passes (2 to 4). The response variables studied were dehulling efficiency, groat recovery and broken content. A linear and second-order quadratic equation was then fitted to the data by multi regression procedure (Alam *et al*., 2008). The design consists of total 17 experiments conducted through run order. All the experiments were conducted in triplicate.

Dehulling of oat grains

Oat samples (2 g) were hand dehulled by picking up individual kernels, one at a time to obtain available groat mass (Knuckle *et al*., 1992). The masses of samples were measured before and after dehulling to calculate the groat percentage. Oat grain samples (1 kg) were mechanically dehulled with the impact dehuller (Lab Impact 1 Oat Dehuller, M/s Creative India Pvt. Ltd., Mohali). Dehulling parameters *viz*., groat recovery (GR), dehulling efficiency (DE) and broken content (BRK) were calculated by applying following formula (Doehlert and McMullen, 2001).

$$GR\,(\%) = \frac{B+G}{W} \times 100$$

$$DE\,(\%) = \left[1 - \frac{H}{w}\right]$$

$$BRK\,(\%) = \frac{B+G}{W} \times 100$$

Where, B = Mass of broken groats (g), G = Mass of whole groats (g), H = Mass of hulled grains remaining (g) and W = The total mass fed into hopper.

Optimization of process parameters

The response surface methodology was applied to the experimental data using commercial software package (Design-Expert DX 9.0.5.1 Stat-Ease, 2018) for optimization of process variables and same software was used for generation of response surface plots. The optimization was done with a goal to maximize groat recovery and dehulling efficiency with minimum formation of brokens during the process, through nonlinear mathematical optimization method. The analysis of variance and regression analysis was carried out independently for each response. The mathematical models were expressed using coded variables for each response by means of multiple regression analysis. Significant terms were found for each response by ANOVA and judged by the F-value calculated from the data (Eren and Kaymak-Ertekin, 2007).

RESULTS AND DISCUSSION

A wide variation in all responses was observed for different experimental combinations, *i.e*., 19.25 to 54.72 % for groat recovery, 8.92 to 24.75 for broken % and 27.14 to 77.01 % for dehulling efficiency respectively (Table 1). The data were analyzed using a multiple regression technique to develop a response surface model. Both dehulling efficiency and broken content were analysed using quadratic model and the groat recovery using linear model. It was observed that the lack of fit was found to be non-significant for all the models. On the other hand, R^2, adjusted R^2, predicted R^2, adequate precision and coefficient of variation were compared with threshold values and confirmed the estimated models to be adequate (Table 2). A second-order polynomial of the following form was fitted to the data for all responses:

$$Y = \beta_o + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 A^2 + \beta_5 B^2 + \beta_6 C^2 + \beta_7 AB + \beta_8 AC + \beta_9 BC$$

Where,

Y= The response variable, predicted responses.

β_o= The intercept.

β_1, β_2, β_3= linear coefficients.

β_4, β_5, β_6= Quadratic coefficients.

β_7, β_8, β_9= Interactions coefficients.

A = Moisture content (%).

B = Feed rate (kg/h).

C = No. of passes.

Effect of different dehulling parameters on responses

The results of the evaluation of different dehulling variables on the responses was analysed and presented in Table 2. Results indicated that grain moisture content, feed rate and number of passes had a significant effect on the dehulling efficiency, groat recovery and broken content.

The predicted models for groat recovery, broken content and dehulling efficiency can be described by the following equation in terms of coded factors:

$$\text{Groat recovery} = 35.19 - 11.57*A - 2.79*B + 9.12*C$$

$$\text{Broken content} = 10.53 - 4.46*A - 0.08*B + 3.17*C - 0.01*AB - 3.45*AC - 0.46*BC + 4.65*A^2 + 3.25*B^2 - 1.37*C^2$$

$$\text{Dehulling efficiency} = 50.91 - 14.12*A - 3.05*B + 11.65*C + 2.60*AB - 2.59*AC - 1.42*BC + 0.06*A^2 + 5.22*B^2 - 2.38*C^2$$

A = Moisture content (%).

Table 1: Box-behnken design and response functions for dehulling of oats.

		Dehulling parameters			Responses		
Exp Nr.	Run	Moisture content % (wb)	Feed rate (kg/h)	No of passes	Groat recovery (%)	Brokens (%)	Dehulling efficiency (%)
1	16	8	6	3	54.72++	24.75++	77.01++
2	13	14	6	3	24.38	12.80	42.29
3	15	8	9	4	53.28	23.69	75.20
4	5	14	12	3	23.32	12.08	40.56
5	9	8	12	3	44.39	24.09	64.87
6	1	14	9	2	19.25+	10.84	27.14+
7	11	8	9	2	34.93	9.80	48.93
8	6	14	9	4	27.78	10.92	43.05
9	2	11	6	2	26.95	8.92+	42.19
10	10	11	9	3	39.21	11.68	52.28
11	3	11	12	2	21.84	10.21	39.77
12	17	11	9	3	32.97	9.69	52.05
13	7	11	12	4	44.52	14.98	62.46
14	4	11	6	4	50.33	15.55	70.55
15	8	11	9	3	32.97	9.69	52.05
16	14	11	9	3	33.73	11.76	49.07
17	12	11	9	3	33.68	9.84	49.08

++ Maximum value and + Minimum value in experimental data.

Table 2: Statistics for various dehulling responses.

Parameters	Groat recovery (%)	Brokens (%)	Dehulling efficiency (%)
Std. Dev.	3.44	1.88	1.92
Coefficient of Variation (%)	9.78	13.83	3.66
R^2	0.9211	0.9460	0.9914
Adjusted R^2	0.9029	0.8766	0.9803
Predicted R^2	0.8499	0.2846	0.9164
Adequate Precision	24.780	11.107	35.095

Table 3: Optimum levels of independent variables and response values.

Predicted solution	Desirability	Moisture content % (wb)	Feed rate (kg/h)	No of passes	GR (%)	BRK (%)	DE (%)
1	0.735	10.62	7.57	4	47.16	14.42	65.79
2	0.735	10.61	7.60	4	47.10	14.40	65.71
3	0.735	10.59	7.57	4	47.24	14.52	65.98
4	0.735	10.65	7.46	4	47.10	14.47	65.97
5	0.735	10.67	7.60	4	46.90	14.24	65.40
6	0.735	10.60	7.73	4	47.05	14.30	65.41
7	0.735	10.71	7.29	4	47.02	14.52	66.18
8	0.700	10.79	10.06	4	44.15	13.14	60.37

B = Feed rate (kg/h).
C = No. of passes.

Groat recovery

The response surface plots showing the effect of process conditions on groat recovery has been illustrated by varying two factors at a time and maintaining one of factors constant to centre level. Fig 1 shows the effect of varying levels of moisture content, feed rate and number of passes on groat recovery. The groat recovery ranged from 19.25 to 54.72% (Table 1). It was observed that increase in grain moisture caused a decrease in groat recovery, this may be because of greater absorption of water in layer between groat and hull which produced an adhesive force. Similar trends for the effect of grain moisture content on groat recovery were reported by Ehiwe *et al*. (1987) for pea. Similarly the increase in feed rate from 6 to 12 kg/h caused a decrease in groat recovery. This trend may be because of with greater feed rate, grains lumped together fell on to the blades of impact dehuller and due to which impact force reduces on to each grain which tends reduction in groat recovery. But as number of passes increased, groat recovery increased. As number of passes increased, remaining hulled grains were dehulled in next repetition, resulted increase in groat recovery. Similar trends of groat recovery were observed by researches conducted by Doehlert and McMullen (2001) and Gupta and Das (1999) for oats and sunflower grains, respectively. Regression coefficients demonstrate that moisture content (A), feed rate (B) and number of passes (C) had significant effect on groat recovery.

Broken content

The Fig 2 shows the effect of varying levels of moisture content, feed rate and number of passes on broken content. With the increase in grain moisture, a decrease in breakage can be observed in 3D plot. The decrease in broken content attributed to greater moisture absorption by inner groats, subsequently induced cohesive force resulted in decline in groat breakage. But as number of passes increases, with repetitive impact groat break down into pieces, as a result broken content increases. Doehlert and McMullen (2001) also observed a decrease in broken % as moisture was increased from 7.5 to 30%. The broken content ranged from 8.92 to 24.75% (Table 1). In this quadratic model linear term of moisture content (A) and number of passes (C), interaction between moisture content and number of passes (AC) and quadratic term of moisture content (A^2) and feed rate (B^2) are significant ($P<0.05$). The negative coefficient of the linear term of moisture content represented a decreasing trend of groat breakage with increase in corresponding factors as shown in Fig 2.

Dehulling efficiency

The response surface plot for dehulling efficiency is presented in Fig 3. The dehulling efficiency ranged from 27.14 to 77.01% (Table 1). Linear term of feed rate (B), interaction terms of moisture content and feed rate (AB) and moisture content and number of passes (AC) and quadratic terms of feed rate (B^2) and number of passes (C^2) werefound significant at $P<0.05$ and linear terms moisture content (A) and number of passes (C) at $P<0.01$. Similar to groat recovery, a decrease in dehulling efficiency was observed with increase in grain moisture and feed rate whereas with increase in number of passes These results for dehulling efficiency are in conformity with results reported by Doehlert and McMullen (2001) for oats.

Optimization of experimental parameters

Based on the models, the optimal working conditions were worked out. The responses dehulling efficiency, groat recovery and broken content were optimized to identify the best conditions that could maximize groat recovery and dehulling efficiency with minimum formation of brokens during the process. By applying desirability function solutions were obtained for the optimum value covering criteria with different desirability values as presented in Table 3. Optimum moisture content, feed rate and number of passes were found to be 10.62% (wb), 7.57 kg/h and 4 passes with maximum desirability of 0.735. Operating under these conditions groat

Table 4: Experimental and predicted values of responses at optimized dehulling conditions.

Response	GR (%)	BRK (%)	DE (%)
Experimental	46.88	14.71	65.53
Predicted	47.16	14.42	65.79

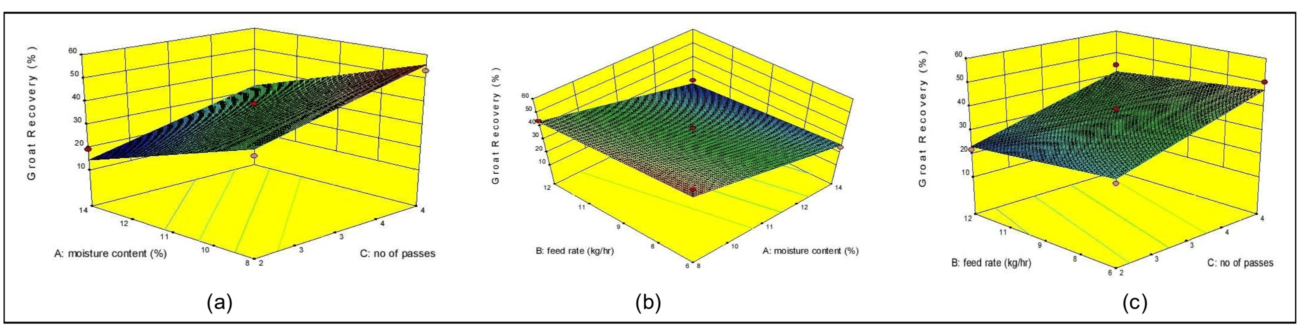

Fig 1: Response surfaces showing the effect of variables (a) moisture content and no of passes (b) feed rate and moisture content (c) no of passes and feed rate on groat recovery.

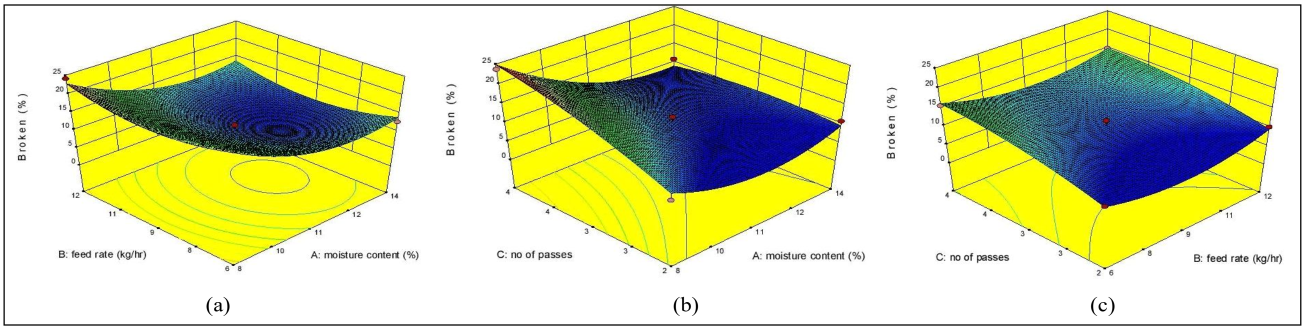

Fig 2: Response surfaces showing the effect of variables (a) moisture content and no of passes (b) feed rate and moisture content (c) no of passes and feed rate on broken content.

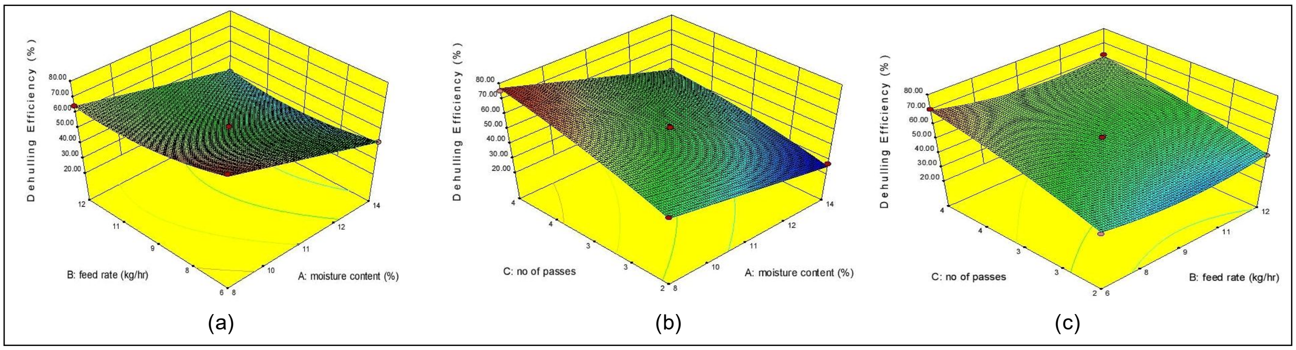

Fig 3: Response surfaces showing the effect of variables (a) moisture content and no of passes (b) feed rate and moisture content (c) no of passes and feed rate on dehulling efficiency.

recovery and dehulling efficiency obtained was 47.88% and 65.53%, respectively generating 14.71% brokens.

To check the validity of the model the experiments were carried out at optimum values of moisture, feed rate and no of passes. The predicted values using obtained models for the three response variables are shown in Table 4. The results indicated that the experimental and predicted values showed a good agreement.

CONCLUSION

The models developed in the present study could be used to estimate the variation of groat recovery and dehulling efficiency in terms of moisture content, feed rate and number of passes. The results showed that maximum groat recovery and dehulling efficiency with lowest fines and broken could be obtained if oat grains with moisture content close to 10.62 % (wb) are fed for 4 times through impact dehuller with a controlled feed rate of 7.57 kg/h. Groat recovery and dehulling efficiency obtained would be 47.16% and 65.79%, respectively generating 14.42% brokens. The models established in this study not only provide an understanding of the interactive effect of processing variables on dehulling characteristics of oat grains but also can be used to select optimal dehulling conditions.

Conflict of interest: None.

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