International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(6): 169-175
© 2018 IJCS
Received: 05-09-2018
Accepted: 10-10-2018

Optimization of dehulling parameters using indigenous oat dehulling machine

Chandan Solanki, Mridula D, SK Aleksha Kudos and RK Gupta

Chandan Solanki
Food Grains & Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Mridula D
Food Grains & Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

SK Aleksha Kudos
Regional Research Centre, ICAR- Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

RK Gupta
Food Grains & Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Correspondence
Chandan Solanki
Food Grains & Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Abstract

Oats (*Avena sativa*) have been used both as food and feed for the last one thousand years. In oat grain, outer hull or husk, which is comprises 25-30% of the weight of the oat grain. Since, it is inedible and not digested by human beings so it should be removed from oats before processing. In India, there is no dehulling technology available for efficient dehulling and further processing of this grains. Based on this an indigenous oat dehuller based on centrifugal action because centrifugal action gave better performance for this grains to remove the resilient, inedible hulls as compared to dehulling with existing machines using abrasion principle. The performance evaluation of the machine was evaluated under three moisture content range (6 to 12 % wb.), impeller speed range (1900 to 2500 rpm) and feed rate range (75 to 225 kg/h) The results of an optimization technique revealed that the best dehulling performance was obtained if the system was operated at impeller speed of 2500 rpm and feed rate of 75 kg/h with moisture content of 6% wb. Under these conditions, the values of dehulling efficiency and percent of broken kernel were 70.42% and 3.64%, respectively.

Keywords: oat, indigenous oat dehuller, moisture content, dehulling efficiency, broken percent

Introduction

Oats (*Avena sativa*) have been used both as food and feed for the last one thousand years. Oats rank around sixth in the world cereal production statistics following wheat, maize rice, barley and sorghum. In 2014, global production of oats was 22.7 million tonnes, led by Russia with 5.3 million tonnes or 23% of the world total with other major producers were Canada, Poland, and Australia. They have been considered as poor man's food and used mainly as porridge, oat meal etc. From the ancient times oats are used as health food because of the excellent nutritional and functional properties and mainly grown in India for fodder purposes only. Oats contain lipids that are rich in unsaturated fats (about 80 percent) and essential fatty acids like linoleic acid. Oats contain unique antioxidants, called avenanthramides, as well as the vitamin E-like compounds, tocotrienols and tocopherols [1]. Oat protein contains considerable quantities of essential amino acids in comparison to wheat [2, 3]. They are an excellent source of soluble fiber in the form of β-glucan. β-glucan is found in the cell walls in oats, has excellent functional properties and is well known for lowering serum cholesterol and blood sugar.

In oat grain, outer hull or husk, which is mainly composed of cellulose, hemicellulose and lignin and it is comprises 25-30% of the weight of the oat grain [2]. Since, it is inedible and not digested by human beings and it should be removed from oats before further processing. Oat dehulling is done by various methods such as manual peeling, stone dehulling, impact dehulling and compressed air dehulling in either batch or continuous mode [4]. These methods vary in efficiency and groat recovery depends upon the dehulling parameters [5]. In India, oat is mainly considered as a feed crop, there is no dehulling technology available for efficient dehulling and further processing of this grains. Although oats are used for preparation of oat flakes, grits and bakery products. At present in India, oat grain is dehulled with traditional methods, this is highly inefficient in terms of product quality and final products.

While performing preliminary trials employing various dehulling methods, it was observed that the dehulling based on the principle of centrifugal action gave better performance for this grains as compared to dehulling of oat grains using rubber roll sheller and dehulling with abrasion method i.e. sorghum pearler which causing a high proportion of brokens in grains. Kaur, J. *et al*., 2014 has also reported dehulling of oat grain variety OL-9 for removal of hulls in multiple passes for achieving maximum dehulled oat.

Centrifugal dehulling is one of the most widely used industrial method for removing the resilient, inedible hulls that cover the groat [6]. Based on this action ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana developed an oat dehuller for dehulling of whole oat. Therefore, this study was carried out to evaluate the performance of this developed oat dehuller machine for dehulling of oat grains. This was done by adjusting the moisture content of the grains, feed rate of the machine, impeller speed and its effect on the dehulling parameters such as dehulling efficiency and brokens.

Materials and Methods

Raw materials

Oat grains (Variety KENT) were obtained from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana for dehulling of this study. Grains were cleaned using cleaner cum grader developed by CIAE, Bhopal (Capacity: 300 kg/h) to remove foreign matters, brokens and immature grains etc. Then stored at room temperature (25±2 °C) in plastic bins for further dehulling study.

Moisture conditioning of grains

Initial moisture content of grains was observed using hot air oven by AOAC method [7] at 105°C for the period until the constant weight reached. Grains were conditioned by mixing calculated amount of distilled water on known weight of grains and storing them in covered plastic bags in refrigerated conditions (4-10°C) with minimum of one week. Oat grains were subjected to conditioning to achieve 12% moisture content (wb). Conditioning was done using the formula (*Myers*, 1971) [8] as below:-

$$Wm = W1\ \{\Delta M / (100 - M2)\}$$

Where Wm is moisture to be added or removed (g), W1 is initial weight of the grain at M1(g), ΔM=M2-M1 (for M2>M1) and ΔM=M1-M2 (for M1>M2), M1 is initial moisture content (wb) and M2 is final or desired moisture content (wb).

Experimental procedure and dehulling of oat grains

The experimental procedure for dehulling of oat grains essentially consisted of three units. These were (1) feed unit, (2) dehulling unit and (3) a drive unit. The dehuller is based on centrifugal action, which is acted on the grains and this force is used for dehulling of the oat grains. The unit consisted of an impeller mounted on a central shaft and was driven by a 0.75 kW single phase DC motor in conjunction with DC drive to regulate the speed of the impeller rotor. The impeller rotor made of 5 forward curved radially pitched mild steed vanes was concentrically positioned within a stationary metal casing of dehulling chamber. Feed rate of the grains was controlled by the closed gate of the hopper to feed the grains to the dehulling unit. In this, conditioned oat grains are fed through a hopper to the centre of a rotating impeller, which is equipped with 5 forward curved impeller vanes or blades. The oats are thrown against an impact ring made of hard material i.e. mild steel that is attached to the housing of the machine. Thus, grains were made to strike against the blades of a fan that operated at high speed to wall of the dehulling chamber, this caused the hull to loosen from its groats, thus releasing the groats. Impeller speed has to be adjusted for achieving high efficiency with minimum breakage to the grains so that, the mixture of groats and separated hull was obtained at an outlet below of the machine. Then mixture of groats, hull and undehulled grains were passed through the aspirator attached with the machine followed by dehulling operation. Aspiration is achieved in such a manner with the pulley arrangements to separate hull and other lighter fraction. The air velocity was adjusted in such a level with the pulley system that only hull were aspirated from the dehulled mass after dehulling of the grains. Finally, the separated dehulled mass was collected at the bottom of the machine. Some amount of hull and undehulled grains were still found mixed with the groats. These were fed to destoner for further sorting of this grains. Then, samples were sealed in polyethylene bags and classified as groats, broken, husk and undehulled oats. With this also, double pass was also be performed after coming out from the aspirator section at optimized parameters and separation of the broken grains was performed thereafter to see the efficiency of this developed dehuller for this oat grains. In this, only unhulled grains were fed to the machine for double pass.

Dehulling efficiency (DE, the ratio of the mass of the dehulled material to that of the feed through the oat dehuller) and broken (% B) were calculated (Singh *et al.* 2009) [14] as given below:

$$DE = \{1 - w_u / F\}\{1 - w_b / F\} \times 100$$

$$B = \{w_b / F\} \times 100$$

Where w_u is the unhulled grains (kg), w_b is the broken kernels after dehulling, F is the whole oat mass fed to the dehuller and B is the percentage of the broken groats.

Statistical analysis

Data obtained was analyzed statistically using response surface methodology with Box-Behnken design (Version 8.0.2). All statistical procedures were performed using this design. Three factor with three replications for each experiment was employed and the means were taken into calculation at $P \leq 0.05$. The experiments were conducted in triplicate. The range of independent variables such as moisture content (6-12% wb), impeller speed (1900-2500 rpm) and feed rate (75-225 kg/h) was chosen based on the performance of the dehulling system. The dehulling efficiency was lower and percentage of broken were more (as the case may be) if the system was operated beyond the chosen limits of independent variables.

For any experimental test, the speed of the impeller rotor and the feed rate of the grain were adjusted individually at their respective level. The machine was allowed to run idle for about 10±15 min to attain a steady velocity. At this time about 0.5 kg of pre-conditioned grain was taken as a sample size (at desired moisture level) and fed to the impeller rotor.

Optimization of process variables (moisture content of grain, feed rate into the dehuller and impeller speed of the rotor) for better performance of the dehulling system using cleaned oat grain was carried out following the Response Surface Methodology (RSM) as described by Myers (1971) [8] and Khuri and Cornell (1987) [9].

Results and Discussion

Effect of impeller speed, grain moisture content and feed rate on dehulling efficiency

The effects of moisture content, impeller speed and feed rate on dehulling efficiency are shown in Figs. 1(a) to (c).The dehulling efficiency at a constant feed rate of 75 kg/h was found to decrease as the moisture content of the grain increased from 6 to 12% wb and the impeller speed of the rotor decreased from 2500 to 1900 rpm. This trend was similar at any impeller speed in this range. Higher dehulling efficiency at low moisture content of the grain might possibly be due to the brittle or fragile nature of the grain hull and the kernel. At higher moisture content of grains, low dehulling efficiency might be due to the higher deformation of grain at specific load which does not rupture the hull during dehulling of oat grain in oat dehuller. Similar deformation trends with moisture content under compressive loading have been observed for melon seed (Makanjuola, 1972) [10], pumpkin seed (Joshi, 1993) [11] and sunflower seed (Gupta, 1999) [12] which reflected in their lower dehulling efficiency in the process of centrifugal dehulling.

The increase in dehulling efficiency was observed with the increase in impellor speed of the rotor from 1900 to 2500 rpm at any moisture content of the grain. The higher dehulling efficiency at higher impellor speed was possibly due to the grain attaining a higher discharge velocity and inducing a larger impact force in the dehuller.

The dehulling efficiency decreased as the feed rate increased from 75 to 225 kg/h (fig. 1(a)) show the effects at moisture content and peripheral speed, respectively. At higher feed rate, the number of grains entering the dehuller per unit time was sufficiently higher, consequently, some grains possibly collided with others instead of impacting on the casing directly. Thus, lower dehulling efficiency of the system resulted. The regression analysis on the experimental results showed a nonlinear relationship among dehulling efficiency, moisture content, feed rate and impellor speed as given below:

D_e (%) $= - 466.47 + 5.62\ M_c + 0.38\ RPM + 1.02002\ FR - 2.14*10^{-4}\ M_c*RPM + 6.58*10^{-3}\ M_c*FR - 3.54\times10^{-4}\ RPM*FR - 0.44\ M_c^2 - 6.92*10^{-5}\ RPM^2 - 1.31*10^{-3}\ FR^2$

$(R^2 = 0.9963)$

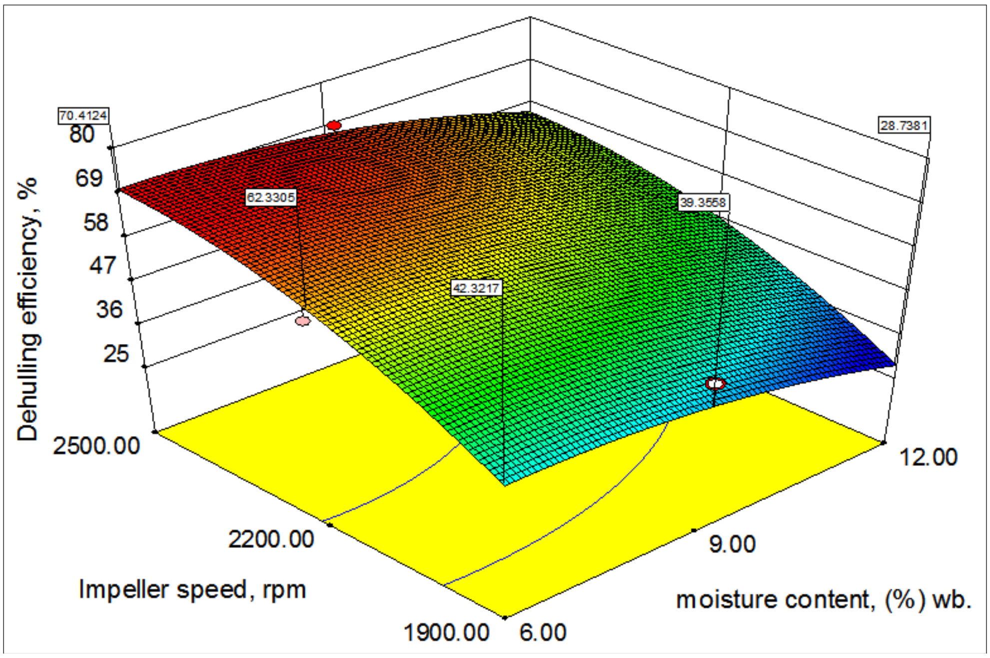

Fig. 1(a)

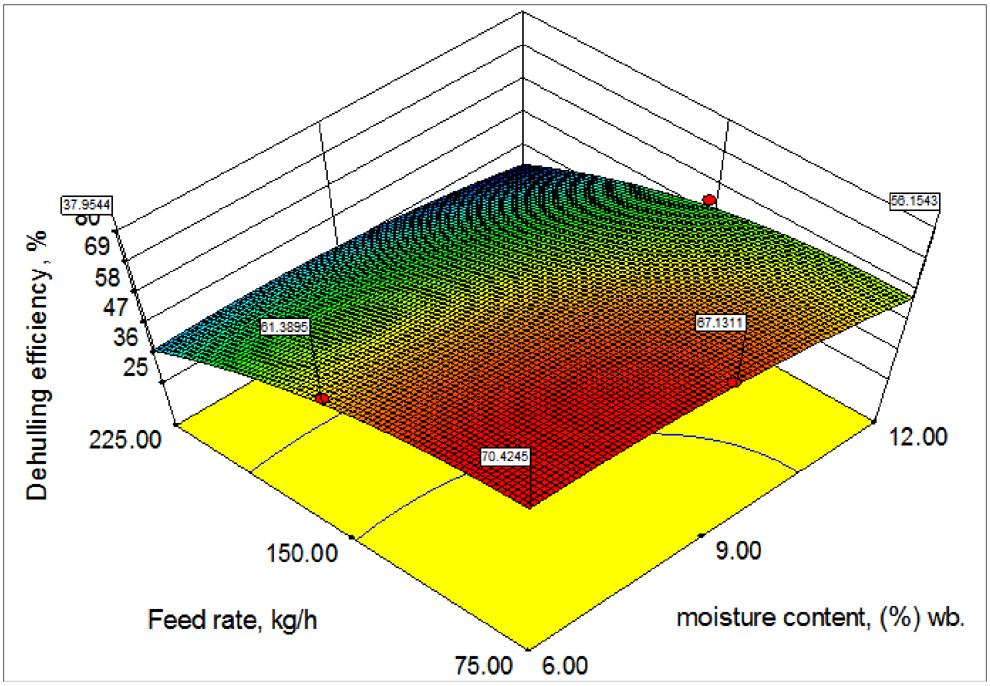

Fig. 1(b)

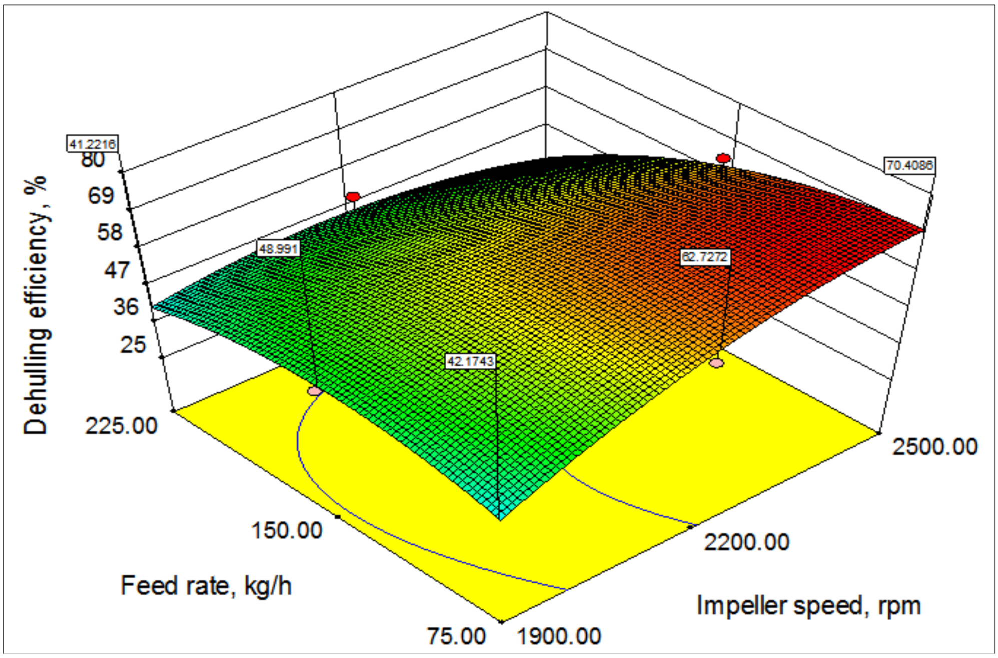

Fig 1(c)

Fig 1: Effect of impeller speed, moisture content and feed rate on dehulling efficiency: (a) at a feed rate of 75 kg/h; (b) at a impeller speed of 2500 rpm; (c) at moisture content of 6%wb.

Effect of impeller speed, grain moisture content and feed rate on percent of broken kernel

The effects of moisture content, impeller speed and feed rate on percent of broken kernel are shown in figs 2 (a) to (c). The percent of broken kernel after dehulling of the grain decreased as the grain moisture content increased from 6 to 12%wb, irrespective of impeller speed and feed rate (Fig. 2(a)). The higher percent of broken kernel at low grain moisture content was possibly due to the kernel becoming brittle and thus more brokens are generated. It increased with the increase in impeller speed for all the grain moisture content and feed rates. It thus implies that, higher impeller speed induces larger centrifugal force on the fragile kernel resulting in more brokens and thereby increasing percent of brokens in kernel fraction. Similar observation was also made by Jain (1980) [13], Joshi (1993) [11] and Gupta (1999) [12] for dehulling of paddy, pumpkin seed and sunflower seed respectively using centrifugal dehuller.

The effect of feed rate on percent of broken kernel is shown in Figs. 2(b) and (c). The percent of broken kernel decreased with increase in feed rate from 75 to 225 kg/h irrespective of the level of moisture content of the grain. Possibly at high feed rate, the motion of grains along the vane of impeller might have been influenced by each other and could result in a reduction in effective forces in dehulling. The percent of broken kernel was found to be non-linearly related to the process variables as follows:

$$B\ (\%) = 1.29 + 0.30\ M_c + 3.09*10^{-3}\ RPM - 0.03\ FR + 2.028*10^{-4}\ Mc*RPM - 5.22*10^{-4}\ M_c*FR + 2.01*10^{-5}\ RPM*FR - 0.05\ M_c^2 - 1.47*10^{-6}\ RPM^2 - 2.88*10^{-5}\ FR^2\ (R^2 = 0.9880)$$

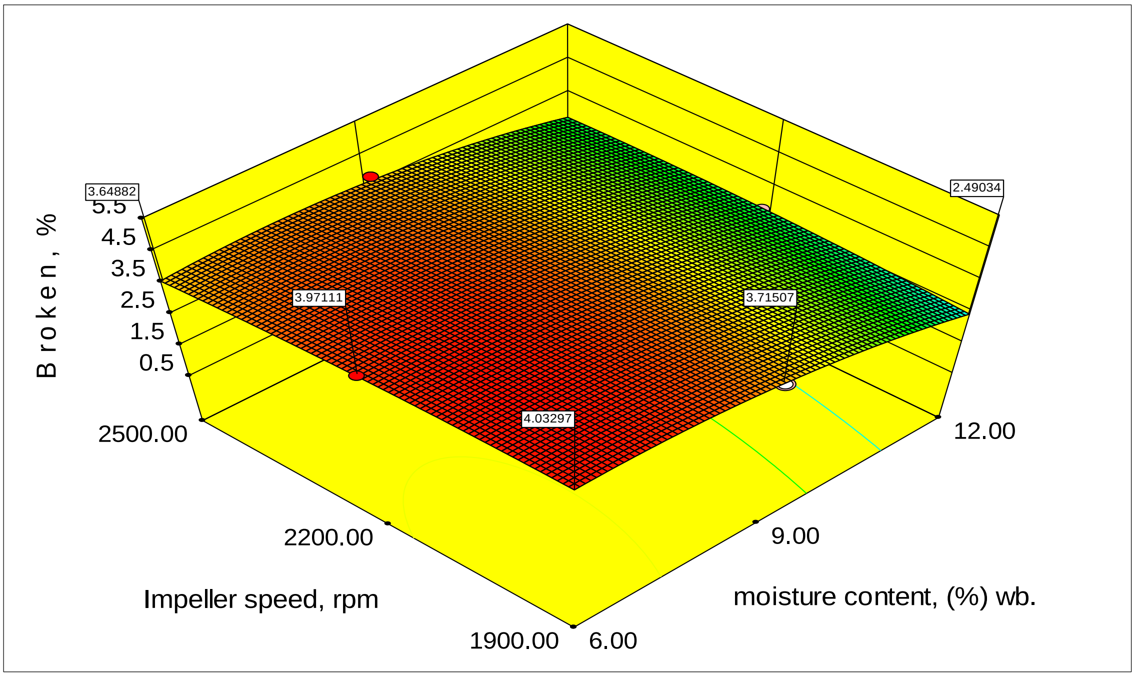

Fig 2(a)

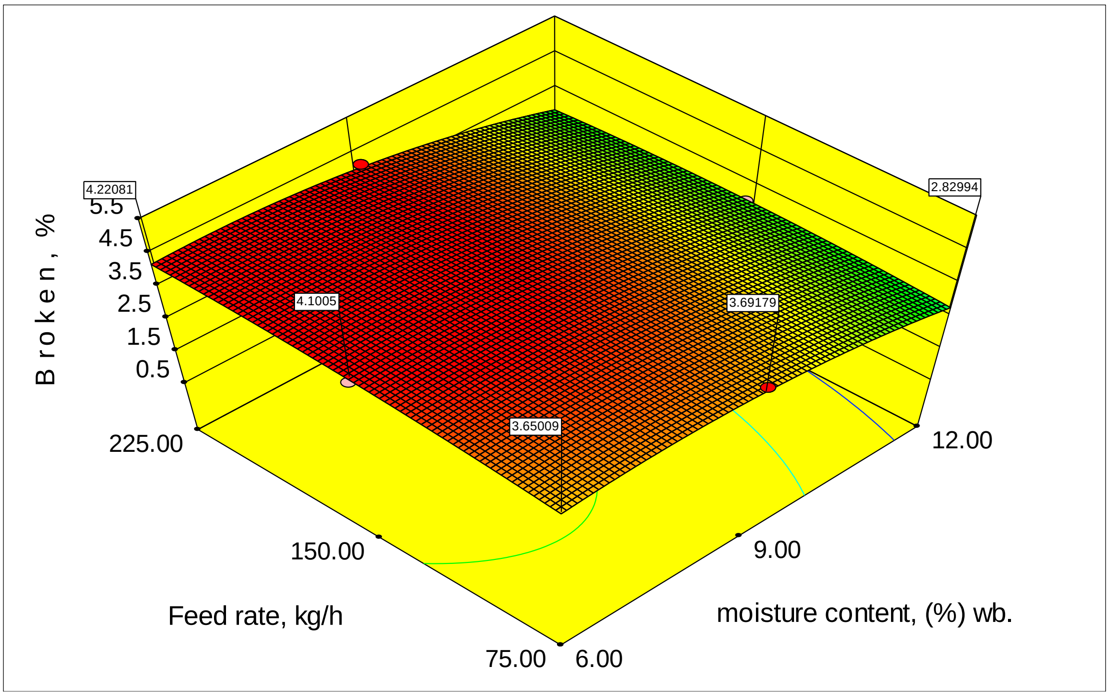

Fig 2(b)

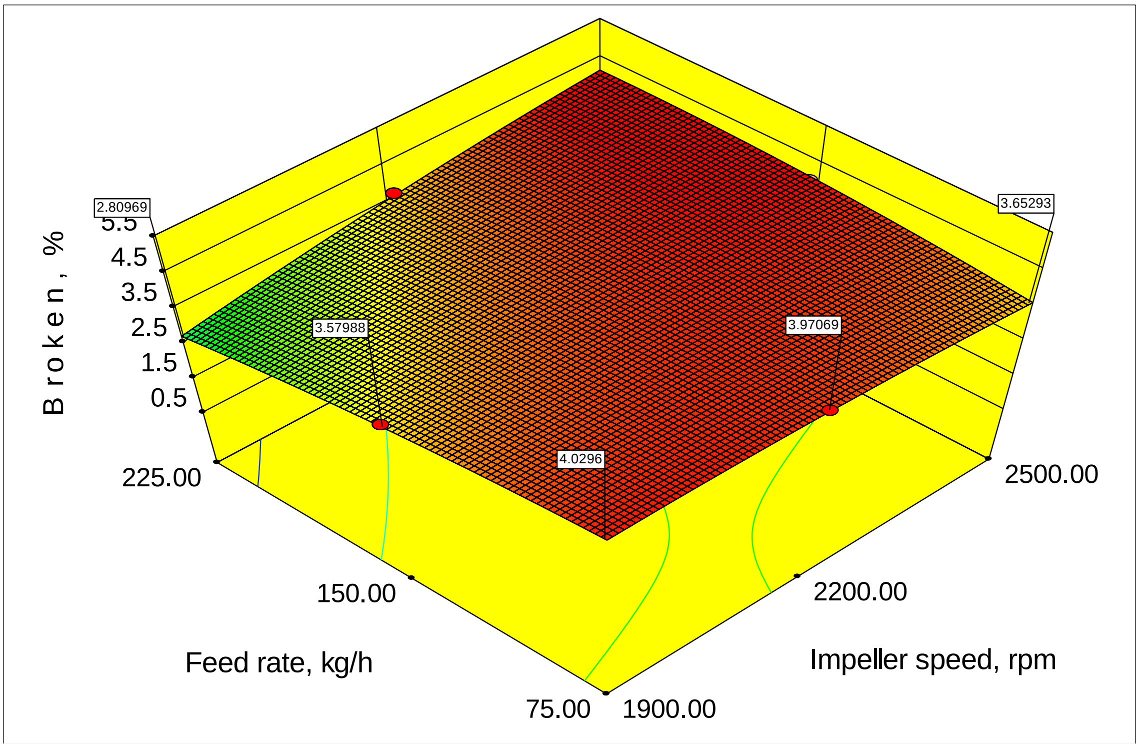

Fig 2(c)

Fig 2: Effect of impeller speed, moisture content and feed rate on percent of broken kernel: (a) at a feed rate of 75 kg/h; (b) at a impeller speed of 2500 rpm; (c) at moisture content of 6%wb.

Analysis of variance

Table 1 shows the effect of all process variables (impeller speed, moisture content, and feed rate) on the response parameters (dehulling efficiency and percent of broken kernel). It is apparent from this table that variation in these factors either individually or in combinations (interactions) significantly influenced the response parameters. Impeller speed, feed rate and moisture content showed the significant effect on dehulling efficiency as well as percent of broken kernel at 5% probability level. The quadratic terms like B^2 and C^2 also show the significant effect on dehulling efficiency and A^2 and C^2 are significant on percent of broken kernel at 5% probability level except the effect of the A^2 was non-significant on dehulling efficiency and B^2 was non-significant on percent of broken kernel at 5% probability level. Since the interaction between B and C was highly significant for dehulling efficiency and interaction between A and B and B and C were highly significant for percent of broken kernel, this indicates the interdependence between these two variables. Deviation in any one of these process variables would affect the dehulling performance to a great extent.

Table 1: Analysis of variance showing the effect of treatment variables as linear term, quadratic term and interactions on the response variables; dehulling efficiency and percent of broken kernel

Source of variance	**F_{cal}**	
	Dehulling efficiency (D_e)	**Percents of broken kernel (B%)**
Linear		
A-Moisture Content	239.26*	4.00*
B-Impeller Speed	294.52*	1.55*
C-Feed Rate	381.29*	0.64*
Qudratic		
A^2	66.61^{ns}	0.86*
B^2	163.16*	0.074^{ns}
C^2	228.86*	0.11*
Interection		
AB	0.15^{ns}	0.13*
AC	8.76^{ns}	0.055^{ns}
BC	253.29*	0.82*
Coefficient of correlation	0.9963	0.9880

*Significant ($p<0.05$).

^{ns}Non significant ($p<0.05$).

Table 2: Optimum values and experimental values of process parameters

Particulars	**Optimum values of process parameters and responses**			
	Target (importance)	**Experimental Range**	**Optimum value**	**Desirability**
Independent variables				
A-Moisture Content, % wb	in range (3)	6-12	6	0.832
B-Impeller Speed, rpm	in range (3)	1900-2500	2500	
C-Feed Rate, kg/h	in range (3)	75-225	75	
Responses			Predicted values	Experimental values
Dehulling efficiency, %	Maximize (3)	31.91-68.78	70.57	68.96
Broken kernel, %	Minimize (3)	1.09-4.09	3.64	3.80

Optimization and validation

To arrive at a reasonable combination of the process parameters for obtaining better dehulling performance, contour plots for the dehulling efficiency and percent of broken kernel for different levels of feed rate and impeller speed were drawn separately for moisture contents of 6, 9 and 12% wb, respectively, keeping the moisture content invariant since, the effect of moisture content on the dehulling efficiency was less significant (see Table 1) than impeller speed and moisture content. Fig. 3 shows such superimposed plot for moisture content of 6% wb (figures for other moisture contents are not shown). Considering the performance of the dehulling system it was decided that the percent of broken kernel should be in the minimum and the corresponding dehulling efficiency should be maximum. The process parameters corresponding to the above response parameters (as indicated by hatched lines in Fig. 3) were noted from the superimposed plots as optimum values for a particular level of moisture content with independent variables were kept within range. The results of optimization technique revealed that the best dehulling performance could be obtained if the system is operated at impeller speed of 2500 rpm and feed rate of 75 kg/h with moisture content of 6% wb indicated the maximum desirability 0.832. Under these conditions, the values of dehulling efficiency and percent of broken kernel would be 70.57% and 3.64%, respectively. This optimized parameters were followed for further validation by analyzing the responses for the grain sample prepared following above optimized process parameters (see Table 2), which have been presented in Table 2. Non-significant validation of results of responses indicated the validity of the optimized parameters at impeller speed of 2500 rpm and feed rate of 75 kg/h with moisture content of 6% wb. With this also dehulling operation was performed in double pass for the oat grains at optimized parameters of the machine to analyze the dehulling efficiency and percent of broken kernel in double pass and it was found, the dehulling efficiency and percent of broken kernel were 85.67% and 6.94% respectively.

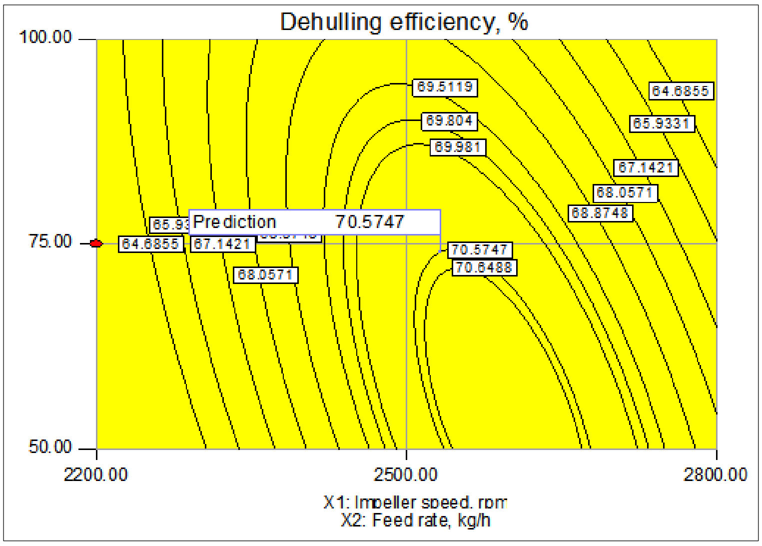

Fig 3: Superimposed contour plot of equal responses at 6% wb moisture content on dehulling efficiency

Conclusions

A mechanical dehulling process based on centrifugal impaction method could be successfully used for dehulling oat grains. The dehulling efficiency decreases as the moisture content of the grain and feed rate increased. The increase in dehulling efficiency was observed with the increase in impeller speed of the rotor. The dehulling efficiency for the grain with 6% wb moisture content was found to be as high as 70.57% at 75 kg/h feed rate and 2500 rpm impeller speed. The percent of broken kernel decreased as the grain moisture content increased irrespective of impeller speed and feed rate. It increased with the increase in impeller speed for all the grain moisture content and feed rates. However, it decreased with increase in feed rate from 75 to 225 kg/h irrespective of the level of moisture content of the grain. The percent of broken kernel was observed to be minimum at grain moisture content of about 12% wb, a feed rate of 225 kg/h and peripheral speed of 1900 rpm. The results of optimization technique revealed that the best dehulling performance could be obtained if the system is operated at impeller speed of 2500 rpm and feed rate of 75 kg/h with moisture content of 6% wb. Under these conditions, the values of dehulling efficiency and percent of broken kernel would be 70.57% and 3.64%, respectively. With this in double pass of the oat grains in this machine, the dehulling efficiency and percent of broken kernel were 85.67% and 6.94% respectively.

References

1. Young VL. Oat lipids and lipid-related enzymes. In: Webster F H (ed) Oats-Chemistry and Technology. American Association of Cereal Chemists St. Paul, MN, USA, 1986.
2. Butt MS, Nadeem MT, Khan MKI, Shabir R, Butt MS. Oat: unique among the cereals. European Journal of Nutrition. 2008; 47(2):68-79.
3. Gambuś H, Gibiński M, Pastuszka D, Mickowska N, Ziobro R, Witkowicz R. The application of residual oats flour in bread production in order to improve its quality and biological value of protein. ACTA Scientiarum Polonorum. 2011; 10:317-25.
4. Doehlert DC, McMullen MS. Optimizing conditions for experimental oat dehulling. Cereal Chemistry. 2001; 78:675-679.
5. Doehlert DC, McMullen MS, Baumann RR. Factors affecting groat percentage in oat. Crop Science. 1999; 39:1858-1865.
6. Ganssmann W, Vorwerck K. Oat milling, processing and storage. In: The oat crop: Production and utilization. Ed R. W. Welch, Chapman and Hall: London, 1995, 369-408.
7. AOAC. Official methods of analysis, 14th edn. Association of Official Analytical Chemists, Washington, 1984.
8. Myers RH. Response Surface Methodology. Bostan: Allyan and Bacon, 1971.
9. Khuri AL, Cornell JA. Response Surface: Design and Analysis. New York: Marcel Dekker, 1987.
10. Makanjuola GA. A study of some of the physical properties of melon seeds. J Agric. Eng. Res. 1972; 12:128-137.
11. Joshi DC. Mechanical dehulling and oil expression of pumpkin seed, Ph.D. thesis. Kharagpur, India: Department of Agricultural and Food Engineering, Indian Institute of Technology, 1993.
12. Gupta RK, Das SK. Performance of centrifugal dehulling system for sunflower seeds, Journal of Food Engineering. 1999; 42:191-198.
13. Jain RK. Optimisation of operating parameters of centrifugal sheller, M. Tech. Thesis. Kharagpur, India: Department of Agricultural and Food Engineering, Indian Institute of Technology, 1980.
14. Singh KP, Mishra HN, Supradip Saha. Moisture dependent properties of barnyard millet grain and kernel. Journal of Food Engineering. 2009; 96:598-606.