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Buckwheat Dehuller and Optimization of Dehulling Parameters

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A B S T R A C T

Pseudo cereals namely Buckwheat (*Fagopyrum esculentum* Moench.) is gluten-free grains characterized by an excellent nutrient profile. They have been used as nutritious ingredients in gluten-free formulations. They have been considered as underutilized food material in India and used mainly used in fasting days. In buckwheat kernel, outer hull or husk, which is comprises about 30% of the weight of the buckwheat grain. Since, it is inedible and not digested by human beings so it should be removed from buckwheat before processing. The performance evaluation of buckwheat dehuller was found to be influenced by the moisture content of the kernel (6 to 9% wb.), roller speed (500 to 1000 rpm) and feed rate (25 k to 75 kg/h). The overall performance was expressed in terms of dehulling efficiency and percent of broken kernel. Dehulling efficiency and percent of broken kernel increased with increase in roller speed up to 800 rpm, increase in feed rate up to 40 kg/h and then decreased further with increase in roller speed and feed rate and decrease in the kernel moisture content. The results of an optimization technique revealed that the best dehulling performance could be obtained if the system is operated at roller speed of 800 rpm and feed rate of 40 kg/h with moisture content of 6% wb. Under these conditions, the values of dehulling efficiency and percent of broken kernel were 66.61% and 6.19, respectively. Second order polynomial equations relating dehulling efficiency and percent of broken kernel to moisture content, impeller speed and feed rates for the buckwheat grains are developed. With this also dehulling operation was performed in double pass for this grains at optimized parameters in 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 74.52% and 10.28% respectively.

Keywords

Buckwheat grains, Buckwheat dehuller and performance evaluation

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Introduction

The traditional staple food from the food grains is available which fulfills the nutritional requirement in the central Himalayas. There are some vegetable cuisines apart from common vegetable only cooked in the Uttarakand hills, which are seasonal, but have medicinal value. One of such vegetable plant *Fagopyrum esculentum* Moench is also known as common buckwheat. In Hindi it is known as Kotu, Phaphra and in Kumaon as ogal belonging to family Polygonaceae. The name "buckwheat" comes from the Anglo-saxon word boc (beech) and whoet (wheat) because the seed resembles a small beech nut. Local people in hilly area of Uttarakhand used it in cooking and on the occasion of festivals, and other religious rituals, dishes are prepared out of it.

Buckwheat, a pseudocereal crop, belonging to the genus *Fagopyrum* of the family Polygonaceae is produced all over the world, Russia and China being the leading producers (*FAO, 2013*). According to FAO estimates, the world production of buckwheat in 2012 amounted to 22,61,550 t from an area of 25,16,035 ha. Commonly two buckwheat species are cultivated: common buckwheat (*Fagopyrum esculentum*) and tartary buckwheat (*F. tartaricum*). Among these two, common buckwheat is the most widely grown species. The grains belong to cereals because of their similar use and chemical composition. It is a crop of secondary importance in many countries. The protein of buckwheat is of excellent quality and is high in essential amino acid lysine, unlike common cereals. It is highly nutritive (63% carbohydrate, 11.7% protein, 2.4% fat, 9.9% fibre and 2% minerals), and is also important as a nectariferous and pharmaceutical plant (*Ratan and Kothiyal, 2011*).

Buckwheat although is grown throughout the Indian Himalayas, and in the Nilgiris and Palni hills of Southern India, its cultivation in the North-Western Himalayan region is more prevalent as a traditional crop (*Dutta, 2004*). It is cultivated by the resource poor mountain farmers far away from assured food distribution system mainly as a food grain crop, and ensures their livelihood and nutritional security. Production data is not available for buckwheat in India, except in the state of Sikkim where the production during 2010-11was 4056.5 t from an area of 4390 ha. However, according to FAO (2013), India is the eighth largest exporter of buckwheat in the world. Buckwheat export from India increased from 153 t in 2010 to 1,782 t in 2011, which is more than 11 fold. In India, Buckwheat grain is consumed by human in a similar manner to cereals, as a leafy vegetable, as animal feed and fodder and also used as a cover crop. Buckwheat flour popularly known as "kuttukaatta" is eaten on fast days, being one of the lawful foods for such occasions. It is also pounded and boiled like rice and consumed as a substitute for rice (Rana, 2004). On the occasion of festivals and other religious rituals, dishes like pakoras, chillare, puwa, halwa and jalebi in India or siland fulaura in Nepal are prepared out of it (*Mehta et al., 2010*).

In buckwheat kernel, outer hull or husk, which is mainly composed of cellulose and it is comprises about 30% of the weight of the buckwheat grain. Since, it is inedible and not digested by human beings and it should be removed from the buckwheat kernel before further processing. Buckwheat dehulling is done by various methods such as manual peeling, stone dehulling and abrasion peeling in batch method. These methods vary in efficiency and groat recovery depends upon the dehulling parameters. In India, buckwheat is mainly considered as a poor mens' crop and there is no dehulling technology available for efficient dehulling and further processing of this grains. Although this grains are used in fasting days in Indian culture. At present in India, buckwheat grainis 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 abrasive action gave better performance for this grains as compared to dehulling of this grains using rubber roll sheller, which causing a high proportion of brokens in grains. Abrasive dehulling is a front-end method to remove the outer layers of seed (*Oomah et al., 1996; Barnwal et al., 2010; Mridula et al., 2012*). In view of this a buckwheat dehuller was developed for efficient dehulling of whole buckwheat. The present study was carried out to evaluate the performance and optimization of machine parameters.

Materials and Methods

Raw materials

Buckwheat grains (*Fagopyrum esculentum*) were obtained from the local market of Ludhiana city of Punjab 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 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. Buckwheat grains were subjected to conditioning to achieve 9% moisture content (wb). Conditioning was done using the formula (*Myers, 1971*) 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 buckwheat grains

The experimental procedure for dehulling of buckwheat grains essentially consisted of three units. These were (1) feed unit, (2) dehulling unit and (3) a drive unit. This dehulleris based on abrasion principle, which is acted on this soft grains andthis friction force is used for dehulling of the buckwheat grains. The unit consisted of horizontally mounted an emery coated rolor with helical pitch on it for conveying the hehulled grains from inlet to outlet section of this machine and was driven by a 0.75 kW single phase DC motor in conjunction with DC drive to regulate the speed of this roller. Feeding rate of the grains was controlledby the closed gate of the hopper to feed the grains to the dehulling section. In this, conditioned buckwheat grains are fed through a hopper to the rotating roller. The buckwheat kernels are dehulled with friction between grain to grain and grain to surface of rotating emery coated roller, this caused the hull to loosen from its groats, thus releasing the groats. Rollor 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 to separate hull and other lighter fraction. The air velocity was adjusted in such a level with motor (0.25 hp single phase AC) system that only hull were aspirated from the dehulled mass after dehulling of the grains. Finally, the separated dehulled and unhulled mass was collected at the bottom of the machine. Some amount of hull and undehulled grains were still found mixed with the groats. Then, these were fed inline to sieves attached for further sorting of this grains. Then, separated mass of hulled fraction were sealed in polyethylene bags and classified as groats, broken, husk and undehulled grains. 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 buckwheat 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 buckwheat dehuller) and broken (% B) were calculated (*Singh et al., 2009*) as given below:

$DE = \{w/ F\}\times100$
$B = \{w_b/ F\}\times100$

Where w is the dehulled grains (kg), w_b is the broken kernels after dehulling, F is the whole buckwheat 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 $P\leq0.05$.

The experiments were conducted in triplicate manner. The range of independent variables such as moisture content (6-9% wb), roller speed (500-1000 rpm) and feed rate (25-75kg/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 operatedbeyond the chosen limits of independent variables.

For any experimental test, the speed of the roller and the feed rate of the grain were adjusted individually at their respective level. The machine was allowed to run idle for about 2±3 min to attain a steady velocity. At this time about 1 kg of pre-conditioned grain was taken as a sample size (at desired moisture level) and fed to the machine.

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

Results and Discussion

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

The effects of moisture content, roller speed and feed rate on dehulling efficiency are shown in Figure. 1(a) to 1(c). The dehulling efficiency at a constant feed rate of 40 kg/h was found to decrease as the moisture content of the grain increased from 6 to 9%wb and the roller speed of the machine decreased from 1000 to 500 rpm. This trend was similar at any roller 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 buckwheat grain in buckwheat dehuller. Similar deformation trends with moisture content under compressive loading have been observed for melon seed (*Makanjuola, 1972*), pumpkinseed (*Joshi, 1993*) and sunflower seed (*Gupta, 1999*) which reflected in their lower dehulling efficiency in the process of dehulling.

The increase in dehulling efficiency was observed with the increase in roller speed from 500 to 1000 rpm at any moisture content of the grain. The higher dehulling efficiency at higher roller speed was possibly due to the grain attaining a higher discharge velocity with increase conveying force and inducing a larger frictions between grain to grain and grain to surface in the dehuller.

The dehulling efficiency increased as the feed rate increased from 25 to 40 kg/hthen again decreased with further increase the feed rate of the grain fed to the machine [Fig. 1(c)] show the effects at roller speed and feed rate, respectively. At higher feed rate up to 40 kg/h, the number of grains entering the dehuller per unit time was sufficiently higher; consequently, grains possibly collided with others and developed frictional force between them. Thus, higher 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 roller speed as given below:

$$D_e\,\% = 72.33 – 2.69M_c + 0.02RPM + 0.01FR + 1.20*10^{-3}\ Mc*RPM\ + 0.01M_c*FR + 7.60*10^{-6}\ RPM*FR - 0.13M_c^2 - 1.24*10^{-5}\ RPM^2 - 1.18*10^{-3}FR^2\ (R^2\ 0.9849)$$

Percentage of broken

The effects of moisture content, roller speed and feed rate on percent of broken kernel are shown in figures 2 (a) to (c). The percent of broken kernel after dehulling of the grain decreased as the grain moisture content increased from 6 to 9%wb, irrespective of roller 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 soft and thus more brokens are generated. It decreased with the increase in roller speed up to 800 rpm then further increased with increasing the roller speed beyond 800 to 1000 rpm for all the grain moisture content and feed rates except 75 kg/h. It thus implies that, higher roller speed induces larger frictional force on the fragile and soft kernel resulting in more brokens and thereby increasing percent of brokens in kernel fraction. Similar observation was also made by *Jain (1980), Joshi (1993) and Gupta (1999)* for dehulling of paddy, pumpkin seedand sunflower seed respectively.

The effect of feed rate on percent of broken kernel is shown in Figures 2(b) and (c). The percent of broken kernel decreased with increase in feed rate from 25 to 40 kg/h then again increased with increasing the feed rate above 40 kg/h irrespective of the level of moisture content of the grain. Possibly at high feed rate beyond 40 kg/h, the motion of grains along the passage between the rollerand inner periphery of dehulling section might have been influenced 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:

$$B\% = +8.76 + 1.34M_c – 0.01\ RPM - 0.07\ FR – 3.87*10^{-4}Mc*RPM – 4.27*10^{-3}M_c*FR + 6*10^{-5}\ RPM*FR - 0.08\ M_c^2 + 9.95*10^{-6}RPM^2 + 5.07*10^{-4}FR^2\ (R^2\ 0.8624)$$

Analysis of variance

Table 1 shows the effect of all process variables (roller 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. Roller speed and moisture content showed the significant effect on dehulling efficiency as well as percent of broken kernel at 5% probability level.

Fig.1 Effect of roller speed, moisture content and feed rate on dehulling efficiency: (a) at a feed rate of 40 kg/h; (b) at a roller speed of 800 rpm; (c) at moisture content of 6%wb

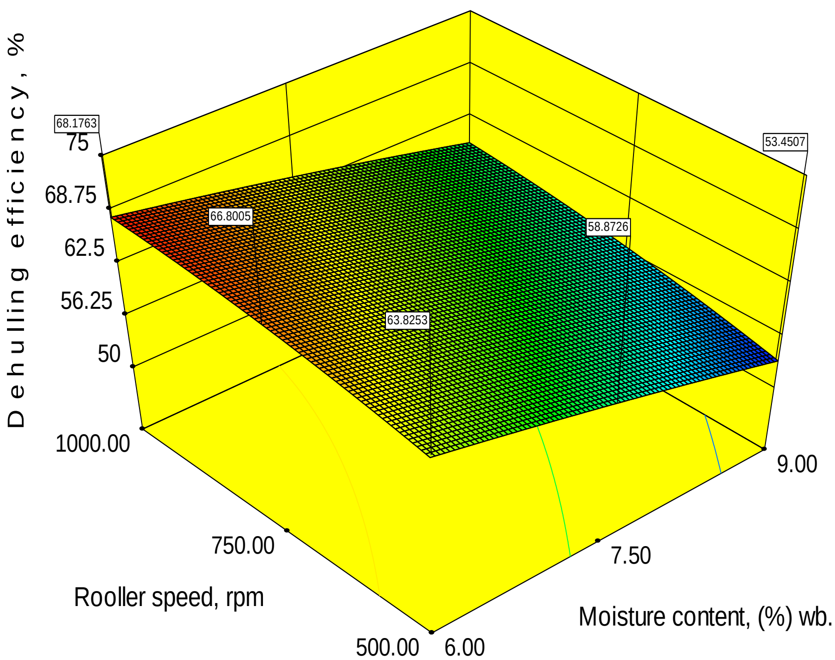

Fig.1 (a)

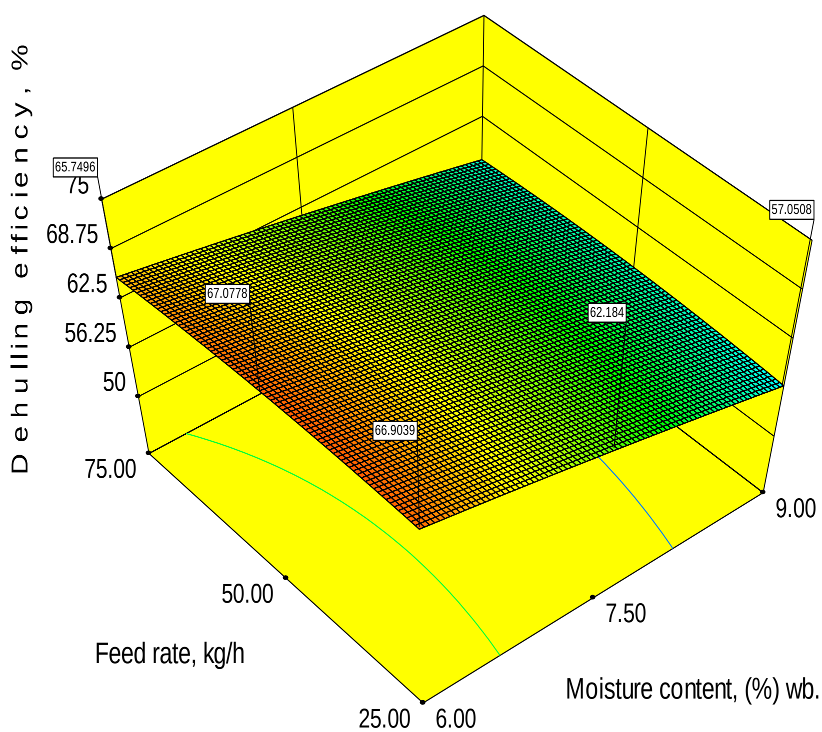

Fig.1 (b)

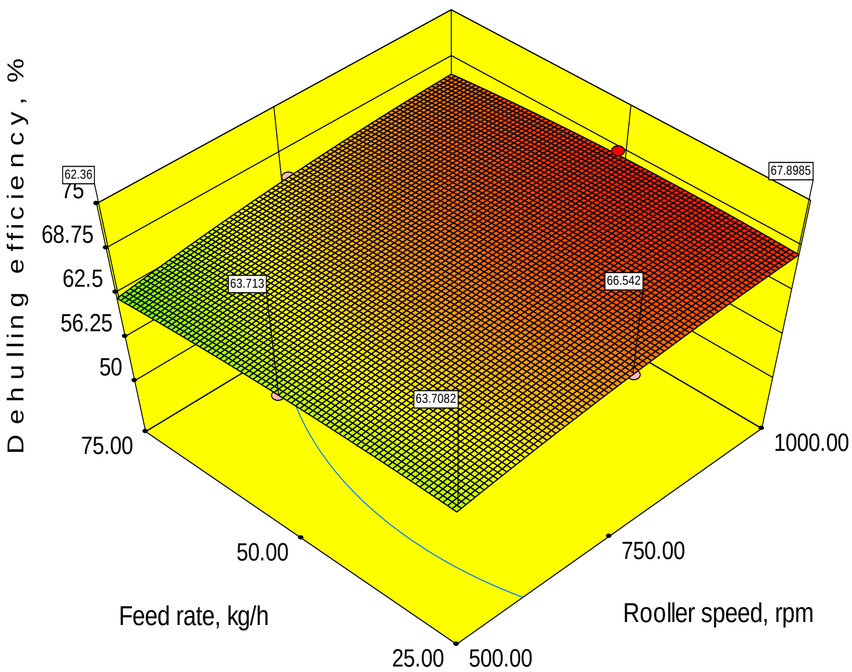

Fig.1 (c)

Fig.2 Effect of roller speed, moisture content and feed rate on percent of broken kernel: (a) at a feed rate of 40 kg/h; (b) at a roller speed of 800 rpm; (c) at moisture content of 6%wb

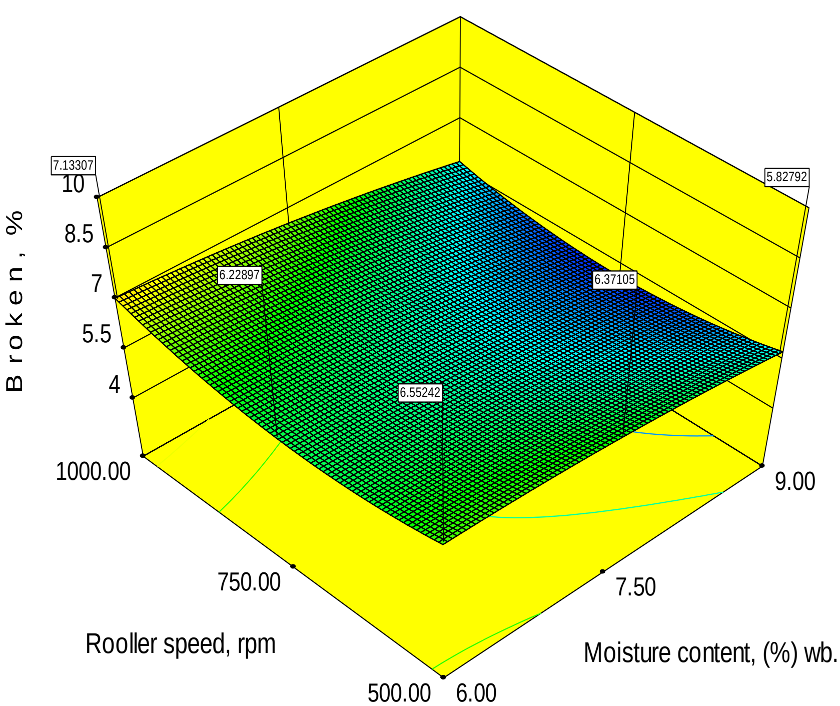

Fig.2 (a)

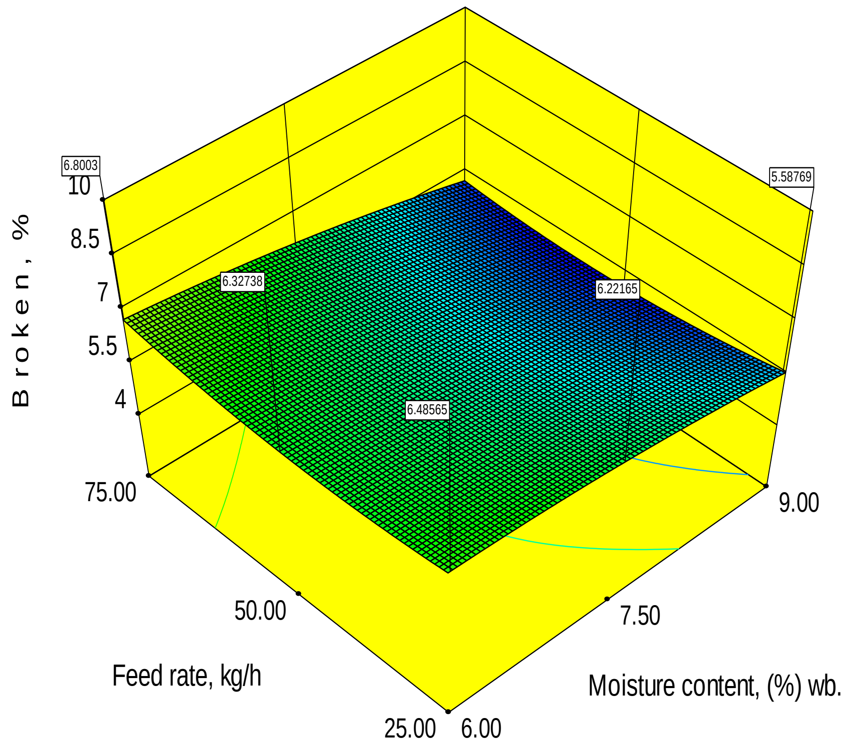
6.8003
5.58769
6.32738
6.22165
6.48565
10
8.5
7
5.5
4
Broken, %
75.00
50.00
25.00
Feed rate, kg/h
6.00
7.50
9.00
Moisture content, (%) wb.

Fig.2 (b)

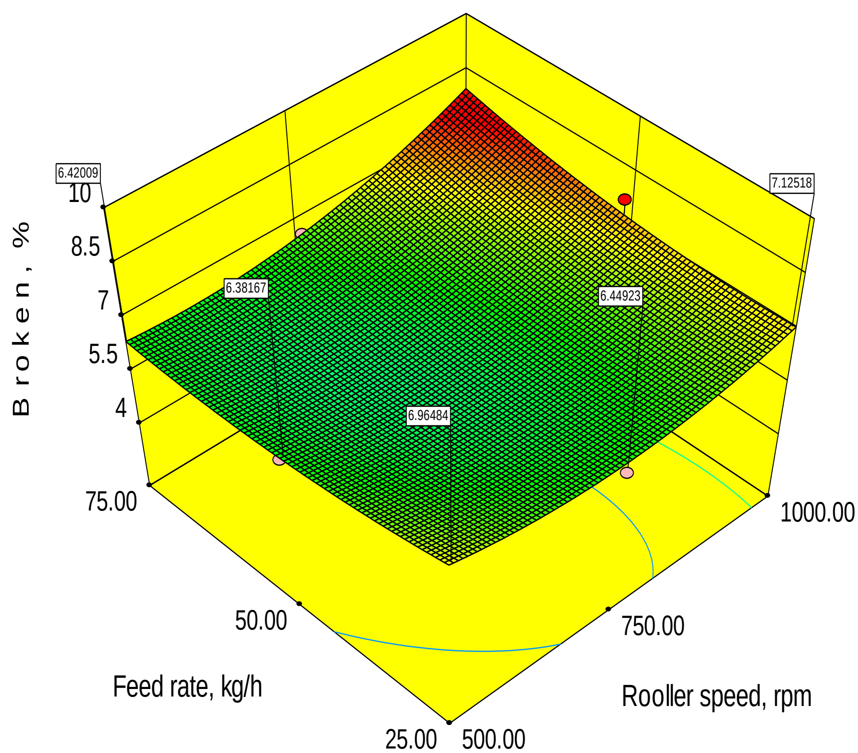
6.42009
7.12518
6.38167
6.44923
6.96484
10
8.5
7
5.5
4
Broken, %
75.00
50.00
25.00
Feed rate, kg/h
500.00
750.00
1000.00
Rooller speed, rpm

Fig.2 (c)

Fig.3 Superimposed contour plot of equal responses at 40 kg/h feed rate on dehulling efficiency

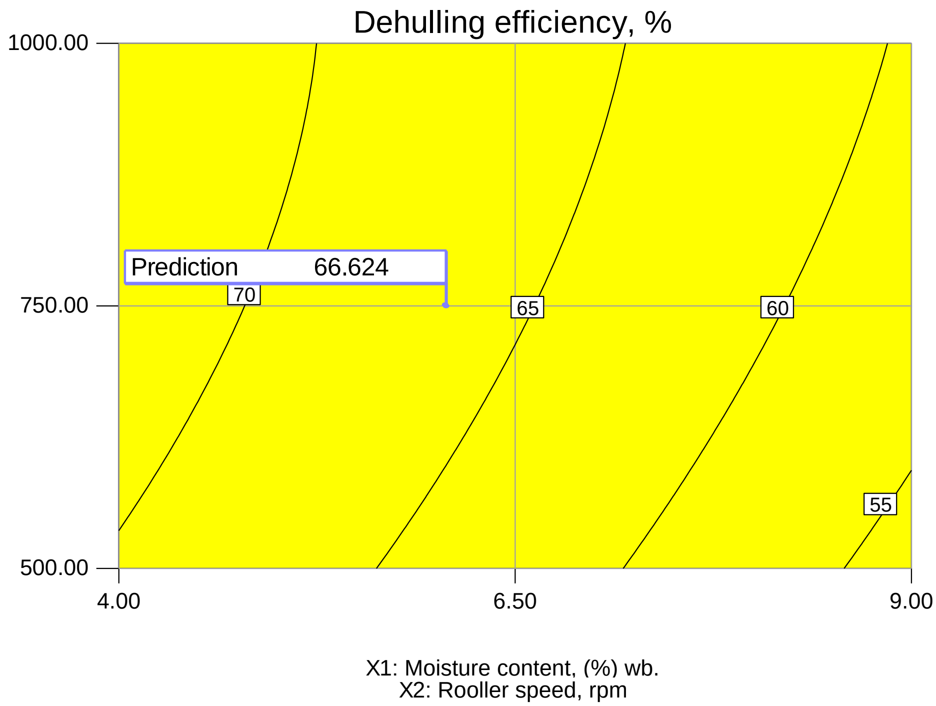

Table.1 Analysis of variance showing the effect of treatment variables as linear term, quadratic term and interactions on the response variables; dehulling efficiency and Percent of broken kernel

Source of variance	F_{cal}	
	Dehulling efficiency (D_e)	**Percents of broken kernel (B%)**
Linear		
A-Moisture Content	169.28*	2.71*
B-Roller Speed	55.49*	0.70^{ns}
C-Feed Rate	0.15^{ns}	0.048^{ns}
Qudratic		
A^2	66.61^{ns}	0.14^{ns}
B^2	163.16^{ns}	0.10*
C^2	228.86^{ns}	0.56^{ns}
Interection		
AB	0.34^{ns}	0.084^{ns}
AC	2.55^{ns}	0.055^{ns}
BC	2.29^{ns}	0.82^{ns}
Coefficient of correlation	0.9849	0.8624

*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	Is in range (3)	6-9	6	0.889
B-Roller Speed	Is in range (3)	500-1000	800	
C-Feed Rate	Is in range (3)	25-75	40	
Responses			Observed values	Experimental values
Dehulling efficiency, %	Maximize (3)	53.13-68.56	66.61	66.55
Percent of broken kernel, %	Minimize (3)	5.12-7.68	6.19	6.40

The quadratic terms like B^2 also showed the significant effect on percent of broken kernel at 5% probability level. Deviation in any one of these process variables would affect the dehulling efficiency as well as percent of broken kernel to a great extent.

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 moisture content and roller speed were drawn separately for feed rate of 500, 800 and 1000 rpm, respectively, keeping the feed rate invariant since, the effect of feed rate on the dehulling efficiency was less significant (see Table 1) than roller speed and moisture content. Figure 3 shows such superimposed plot for feed rate of 800 rpm (figures for other feed rates are not shown). Considering the performance of the dehulling system it was decided thatthe 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 feed rate 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 roller speed of 800 rpm and feed rate of 40 kg/h with moisture content of 6% wb indicated the maximum desirability 0.889. Under these conditions, the values of dehulling efficiency and percent of broken kernel would be 66.61%and 6.19%, 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 roller speed of 800 rpm and feed rate of 40 kg/h with moisture content of 6% wb. With this also dehulling operation was performed in double pass for the buckwheat 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 74.52% and 10.28% respectively.

A mechanical dehulling process based on frictional method could be successfully used for dehulling buckwheat grains. The dehulling efficiency decreases as the moisture content of the grain increased in this range. Dehulling efficiency increases as the feed rate increased up to 40 kg/h and again decreases beyond this feed rate up to 75 kg/h. The increase in dehulling efficiency was observed with the increase in roller speed of the roller. The dehulling efficiency for the grain with 6%wb moisture content was found to be as high as 66.61% at 40 kg/h feed rate and 800 rpm roller speed. The percent of broken kernel decreased as the grain moisture content increased irrespective of roller speed and feed rate. It decreased with the increase in roller speed up to 800 rpm for all the grain moisture content and further increased beyond the roller speed in this range. However, it decreased with increase in feed rate from 25 to 40 kg/h then again increased 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 9%wb, a feed rate of 40 kg/h and peripheral speed of 800 rpm.

The results of optimization technique revealed that the best dehulling performance could be obtained if the system is operated at roller speed of 800 rpm and feed rate of 40 kg/h with moisture content of 6% wb. Under these conditions, the values of dehulling efficiency and percent of broken kernel would be 66.61% and 6.19%, respectively. With this in double pass of the buckwheat grains in this machine, the dehulling efficiency and percent of broken kernel were 74.52% and 10.28% respectively.

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