IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 6 Issue 2, February 2019
ISSN (Online) 2348 – 7968
www.ijiset.com

Influence of Rotational Speed and Feed Rate on Fennel Seed Extraction Efficiency

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ABSTRACT

Spices seed extractor was developed during 2015-18 to extract the seeds from fennel plant and flowers. The spices seed extractor was operated by 2 hp single-phase electric motor. The developed spices seed extractor consist of feeding hopper, extraction unit, sieve/cleaning unit, main frame and power transmission system. Machine and operational parameters were optimized for fennel seed extraction to achieve higher seed extraction efficiency. The optimized machine and operational parameters for fennel seed minimum seed damage during fennel seed extraction were found to be stud bolted type drum having rotational speed of 700 rpm and feed rate of 180 kg/h. The seed damage during fennel seed extraction was found to be 2.84 per cent at optimized machine parameters.

Keywords: Spices seed extractor, fennel, extraction efficiency

INTRODUCTION

India is the second largest vegetable producer, producing 99.4 million tones of different vegetables. The application of suitable seed extractor in the advancement of extraction process will facilitate production of healthy seed and will set higher standards for various parameters (Khushwaha, 2005). The area and production of fennel during 2016-17 was 74660 ha and 124610 tonnes, respectively. Fennel is considered to be one of the most important medicinal and aromatic plants. Fennel can be used as antispasmodic, carminative and for the relief of epigastric pain, intestinal cramps and colics especially for infants. Its roots are also used as laxative and diuretic. Fennel oil is used in manufacturing of condiment, perfumes, soap and as a food flavor. Commercial fennel varies greatly in quality, this being either due to lack of care in harvesting or deliberate adulterate. It may contain dust, stem tissues, weed seeds and other materials.

Seed extraction/separation and cleaning is an important operation in a number of processes connected with the handling of seed after harvest. It is impossible to grow and

harvest seed crops without getting undesirable intermixtures despite proper care and tending of the crop. These intermixtures may comprise weed seeds, other crop seeds, and various inert matter as well as undeveloped seeds of species in question.

Traditional method of seed separation/extraction involve various operations like harvesting, sun drying, beating and winnowing. Operations being carried out manually, it takes more time and seed obtained by this method is of poor quality. Also presently no mechanical extractor is available for extraction and cleaning of fennel seed. The spices seed extractor was developed for extraction of spices such as fennel seeds mechanically. It was necessary to optimize the machine and operational parameters. Hence, the work was undertaken to optimize the machine and operational parameters for maximum extraction efficiency.

MATERIAL AND METHODS

The fully matured fennel crop with well dried flowers of variety AF 101 available at the field of Chilli and Vegetable Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola were used for conducting the experiments on fennel seed extraction .

Spices seed extractor

The spices seed extractor was developed in the workshop of AICRP on Post Harvest Engineering and Technology and Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola and was used for the extraction of ajwain seeds. The spices seed extractor consisted of the following major units viz., i) Feeding hopper ii) Seed extraction unit iii) Sieve/Cleaning unit iv) Main frame and v) Power transmission system.

Plate 1. Spices seed extractor

Optimization of parameters for extraction of ajwain seeds

Three types of extraction drums were fabricated for the experiments. The developed spices seed extractor was tested as per standard procedures for combination of various treatments. Based on feeler trials, some of the machine and operational parameters such as concave clearance, sieve aperture size and blower/fan speed were finalized for fennel crop and were kept constant throughout the complete experimentation. Experiments were conducted to optimize the design parameters such as type of seed extraction mechanism (stud bolted drum, loop type drum, leather flap drum) and the operational parameters such as rotational speed and feed rate. Fennel crop samples each weighing 2 kg and having about 10 ± 0.5 % moisture content (w.b.) were used for extraction using the developed spices seed extractor. After seed extraction all the fractions at each outlet were collected in the separate containers. Each of the sample was analyzed for extracted seed, unextracted seed, chaff, etc. Care was taken to obtain all the fractions without any loss.

The variables of seed extraction experiments were optimized using Response Surface Methodology technique, since this is useful statistical technique for investigation of complex processes. RSM is a collection of certain statistical techniques for designing experiments, building models, evaluating the effects of the factors and searching for optimal conditions for desirable responses (Cochran and Cox, 1957; Box *et al.*, 1978 and Myers *et al.*, 2009). The response surface analysis involves fitting the experimental values of seed extraction efficiency and seed loss to a general quadratic polynomial equation and subsequently optimizing the values with suitable optimization software or mathematical solutions. The studies of optimization have been carried out by various research workers (Pokharkar, 1994; Vijayan and *et al.*, 1995; Chowdhary *et al.*, 2000; Kar and Gupta, 2001; Liyana-Pathirana and Shahidi, 2005; Eren and Kaymak-Ertekin, 2007; Jain, 2007; Altan *et al.*, 2008; Corzo *et al.*, 2008; Mestdagh *et al.*, 2008; Shi *et al.*, 2008 and Borkar, 2011).

Optimization of Seed Extraction Unit

The type of seed extraction drum, rotational speed and feed rate were optimized for minimum seed damage.

Treatment Details

Independent variables

Categoric factors

Types of seed extraction drums-Stud bolted drum ii. Loop type drum iii. Leather flap drum

Rotational speed of seed extraction drum (R), rpm - 600 ii. 650 iii. 700 iv. 750 v. 800

Feed rate (F), kg/h - 60 ii. 120 iii. 180 iv. 240 v. 300

Dependent variable

i. Extraction efficiency

The extraction efficiency was calculated using the following formula.

Extraction efficiency, % = 100 – un-extracted seed

$$\text{Unextracted seed (\%)} = \frac{\text{Weight of unextracted seed, g}}{\text{Weight of total seed input, g}}$$

……(1)

Optimization of seed extraction drum for fennel seed extraction

Optimization of seed extraction drum for fennel seed extraction is necessary so that maximum extraction efficiency could be achieved. Different types of seed extraction drums viz stud bolted drum, loop type drum and leather flap drum were tested for extraction of seeds out of which one drum was optimized based on maximum extraction efficiency. The experimental layout for two variable five levels response surface analysis as shown in Table 1 was used.

Design of experiments

The method of response surface deals with the problem of seeking the conditions of an experiment, which are optimal, i.e., most desirable. The techniques applied here are standard techniques, which have been described in greater detail by Myers (1971). Numeric factors are the common ones used and they can be easily adjusted to any level over a continuous operating range. The introduction of categoric factors to RSM increases the complexity of the design exponentially (Mark and Patrick, 2005). This causes the number of runs generated to be multiplied by the number of combinations of the categorical factor levels. Experimental layout for two variables and five levels response surface analysis is shown in Table 1.

Extraction Data Analysis

Response Surface Methodology (RSM) was applied to the experimental data using Design-Expert version 9 (Statease Inc, Minneapolis, USA, Trial version, 2017).

Table 1. Levels of independent variables for fennel seed extraction

Independent variables	Symbols		Levels	
	Coded	Decoded	Coded	Decoded
Rotational speed, rpm	x_1	X1	2	800
			1	750
			0	700
			-1	650
			-2	600
Feed rate, kg/h	x_2	X2	2	300
			1	240
			0	180
			-1	120
			-2	60

The Central Composite Design of two variables and five levels including thirteen trials was used for each type of extraction drum. As per this design, total 39 trials were performed for all the three type of seed extraction drums.

RESULTS AND DISCUSSION

The parameters such as type of seed extraction drum, rotational speed and feed rate were required to be optimized for maximum seed extraction efficiency and minimum seed damage. During preliminary experiments, extraction efficiency was found to be dependent on the machine and operational parameters. Based on feeler trials, concave clearance and blower/fan speed were finalized and were kept constant throughout the complete experimentation. Moisture content at the appropriate time of extraction was measured and was in the range of 10 $\pm$ 0.5 per cent on wet basis.

Results and discussion

Effect of variables on seed damage during fennel seed extraction

The results obtained for per cent seed damage during the experimentation on fennel seed extraction using the developed spices seed extractor revealed that the seed damage was observed to be ranging from 2.58 to 4.15 per cent depending upon the extraction treatments. The maximum seed damage was observed in case of treatment having the combination of leather flap drum, rotational speed of 800 rpm and feed rate of 300 kg/h. The minimum seed damage was found for treatment having the combination of stud bolted drum, rotational speed of 700 rpm and feed rate of 180 kg/h. The fennel seed damage was found to be dependent on the type of seed extraction drum, rotational speed and feed rate.

A second order polynomial equation fitted with the experimental data gives the predicted mechanical seed damage (%) as a function of drum rotational speed (R) and feed rate (F). This equation was obtained using step down regression method where factors with F-values less than one were rejected as described by Snedecor and Cocharan (1967). The data for seed loss were analyzed for stepwise regression analysis and the analysis of variance (ANOVA) is shown in Table 2. The response surface reduced cubic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic effects were analyzed for mechanical seed damage which gives the effect of various parameters on seed damage.

For fennel seed damage, the model F- value of **7.73** implies that the model is significant ($P<0.01$). The linear terms (R and F) are significant ($P<0.01$). The lack of fit F-value was non significant, which indicated that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of **0.5511** was in reasonable agreement adjusted R^2 of **0.7508**. This revealed that the non-significant terms have not been included in the model. Therefore, this model could be used to navigate the design space. High value of coefficient of determination ($R^2 = 0.8623$) obtained for response variable indicated that the developed model for extraction efficiency accounted for and adequately explained **86.23%** of the total variation.

Regarding the effect of independent parameter, from analysis of variance (ANOVA) given in Table 5.21, among linear effects the type of drum had significant effect on seed damage ($P<0.01$) at 1 % level of significance followed by rotational speed followed by feed rate. The existence of quadratic terms indicated the curvy linear nature of response. It

indicated that increasing the value of variable initially increased the response up to certain level of variable however further increase in the level of variable decreased the value of response.

Table 2 ANOVA for effect of extraction treatment variables on fennel seed damage

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.50	17	0.2057	7.73	< 0.0001	Significant
A-Rotational Speed	0.1692	1	0.1692	6.36	0.0198	
B-Feed rate	0.5774	1	0.5774	21.71	0.0001	
C-Type of extraction drum	1.75	2	0.8773	32.99	< 0.0001	
AB	0.0800	1	0.0800	3.01	0.0974	
AC	0.0231	2	0.0115	0.4336	0.6539	
BC	0.0833	2	0.0417	1.57	0.2323	
A^2	0.3127	1	0.3127	11.76	0.0025	
B^2	0.1535	1	0.1535	5.77	0.0256	
ABC	0.0746	2	0.0373	1.40	0.2680	
A^2C	0.1410	2	0.0705	2.65	0.0940	
B^2C	0.2083	2	0.1041	3.92	0.0359	
Residual	0.5585	21	0.0266			
Lack of Fit	0.1708	9	0.0190	0.5876	0.7845	not significant
Pure Error	0.3876	12	0.0323			
Cor Total	4.06	38				

Std. Dev.	0.1631		**R^2**	0.8623
Mean	3.44		**Adjusted R^2**	0.7508
C.V. %	4.74		**Predicted R^2**	0.5511
PRESS	1.82		**Adeq Precision**	10.0644

Final equation in terms of coded values

The response surface equation was obtained for the model of second degree in terms of coded factors as under.

Seed damage = $+3.31+0.0840*A+0.1551*B-0.4287*C+0.2473*C^2+0.0817*AB-0.0045*AC-0.0355*(AC)^2+0.0820*BC-0.0282*BC^2+0.1224*A^2+0.0858*B^2-0.0917*ABC+0.1008*(ABC)^2-0.1143*A^2C+0.1373*B^2C-0.0976*(B^2C)^2$

……..(2)

The equation 2 in terms of coded factors can be used to make predictions about the response for given levels of each factor.

Final Equation in Terms of Actual Factors

The response surface equation for fennel seed damage according to drum type was obtained for the model of second degree in terms of actual factors as under.

Stud bolted drum (D_1)

Seed damage = $+21.79155 -0.054016*R -0.007189*F-1.66667E-06*R*F +0.000040*R^2 +0.000031*F^2$ ……..(3)

Loop type drum (D_2)

Seed damage = $+7.38650 -0.007065*R -0.019202*F+0.000030*R*F+1.62500E-06*R^2 - 1.64931E-06*F^2$ ……..(4)

Leather type drum (D_3)

Seed damage = $+19.57208 -0.045537*R - 0.009571*F +0.000012*R*F+0.000032R^2++6.40625E-06*F^2$ ……(5)

Where,
R = Rotational speed, rpm
F = Feed rate, kg/h

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. The linear positive term in equation 2 indicated that the seed damage increased with increase in rotational speed. The negative value of

quadratic terms of rotational speed and feed rate indicated that high value of these variables further increased the seed damage.

To visualize the combined effect of two variables on the seed damage, the response surface contour plots (Fig 1 to 3) were generated for the fitted model as a function of two variables while keeping the third variable at its central value.

Effect of rotational speed and feed rate on fennel seed damage

The effect of rotational speed and feed rate on seed damage is shown in Fig 1 to 3. The seed damage was found to be slightly decreased with increase in rotational speed up to certain limit in all type of seed extraction drums. Fig 1 to 3 shows that as the rotational speed increased, the seed damage slightly decreased up to certain maxima and if rotational speed is further increased beyond this level, the seed damage was observed to be increased significantly. Significant effect of rotational speed was observed on seed damage. This might be due to the reason that at higher rotational speed, the friction between the seed extraction drum and the seed is more than the required which resulted in increased seed damage.

The seed damage was found to be decreased with increase in feed rate in all type of seed extraction drums. Fig. 1 to 3 shows that as the feed rate increased, the seed damage was found to be decreased. As the feed rate increased beyond specific level, the seed damage was found to be increased. This might be due to the fact that excess feeding of raw material needed more time for complete seed extraction remained in the contact of extraction mechanism for more time which resulted in higher damage.

It was observed that the stud bolted drum was found to be most efficient for causing less damage to the seeds with respect to input parameters such as rotational speed and feed rate as compared to loop type drum and leather flap drum.

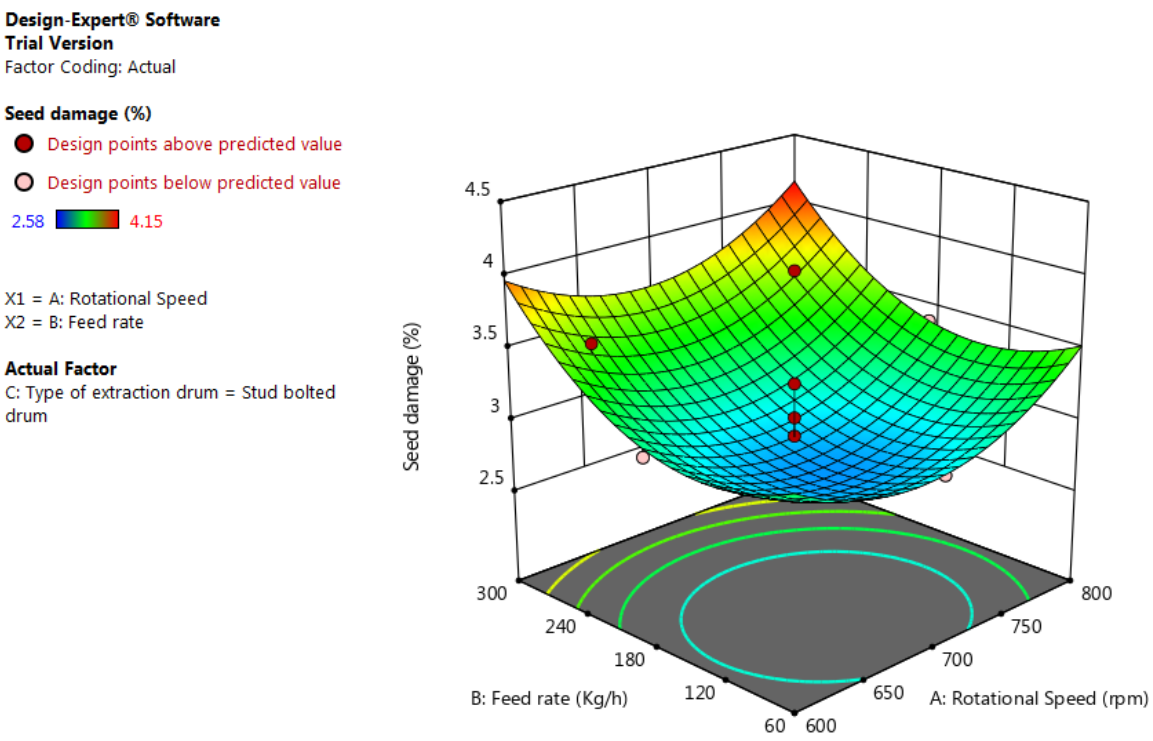

Fig. 1 Effect of rotational speed and feed rate on fennel seed damage

(Stud bolted drum)

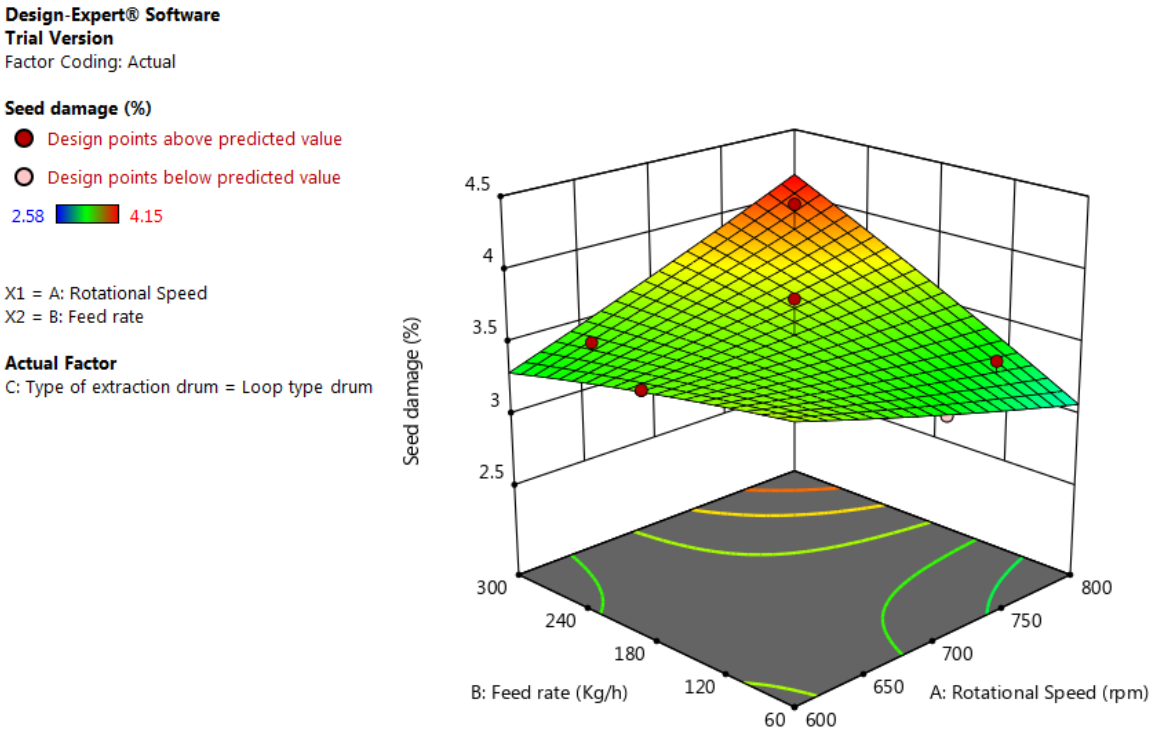

Fig. 2 Effect of rotational speed and feed rate on fennel seed damage

(Loop type drum)

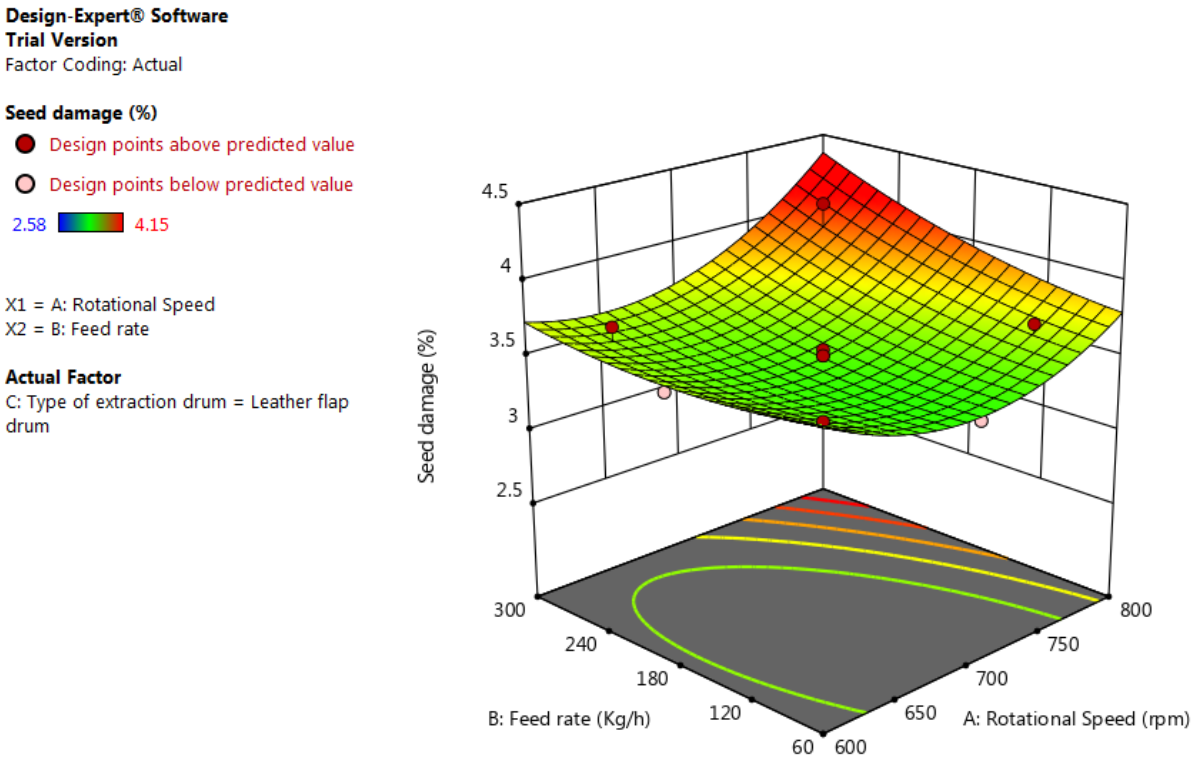

Fig. 3 Effect of rotational speed and feed rate on fennel seed damage

(Leather flap drum)

Table 3. Optimized solution generated by the software for fennel seed damage

Number	Rotational drum speed, rpm	Feed rate, kg/h	Drum type	Mechanical seed damage, %	Desirability	
1	709.22	172.47	Stud bolted drum	2.87	0.895	Selected

Considering the structure of seed, flower and stem, stud bolted drum was found better for extraction of fennel seeds as compared to loop type and leather flap drum. The optimized input parameters for the seed damage were found to be:

The optimized input parameters for the seed damage (Table 5.24) were found to be:

Rotational speed (rpm) = 709.22 ~ 700

Feed rate (kg/h) = 172.47 ~ 170

Type of drum = Stud bolted drum

The predicted seed damage observed to be 2.87% (Table 5.24).

A graphical multi response optimization technique was adapted to workable optimum machine parameters for fennel seed damage. The contour plots for all responses were selected as optimum conditions. These constraints resulted in feasible zone of the optimum solutions (colored area in the superimposed contour plots). Superimposed contour plots having common superimposed area for all responses are shown in Fig. 4.

The superimposed contours of response for rotational speed and feed rate and their intersection zone for minimum seed damage indicate range of optimum values of operational parameters as below.

Rotational speed, rpm = 630-740

Feed rate, kg/h = 180-210

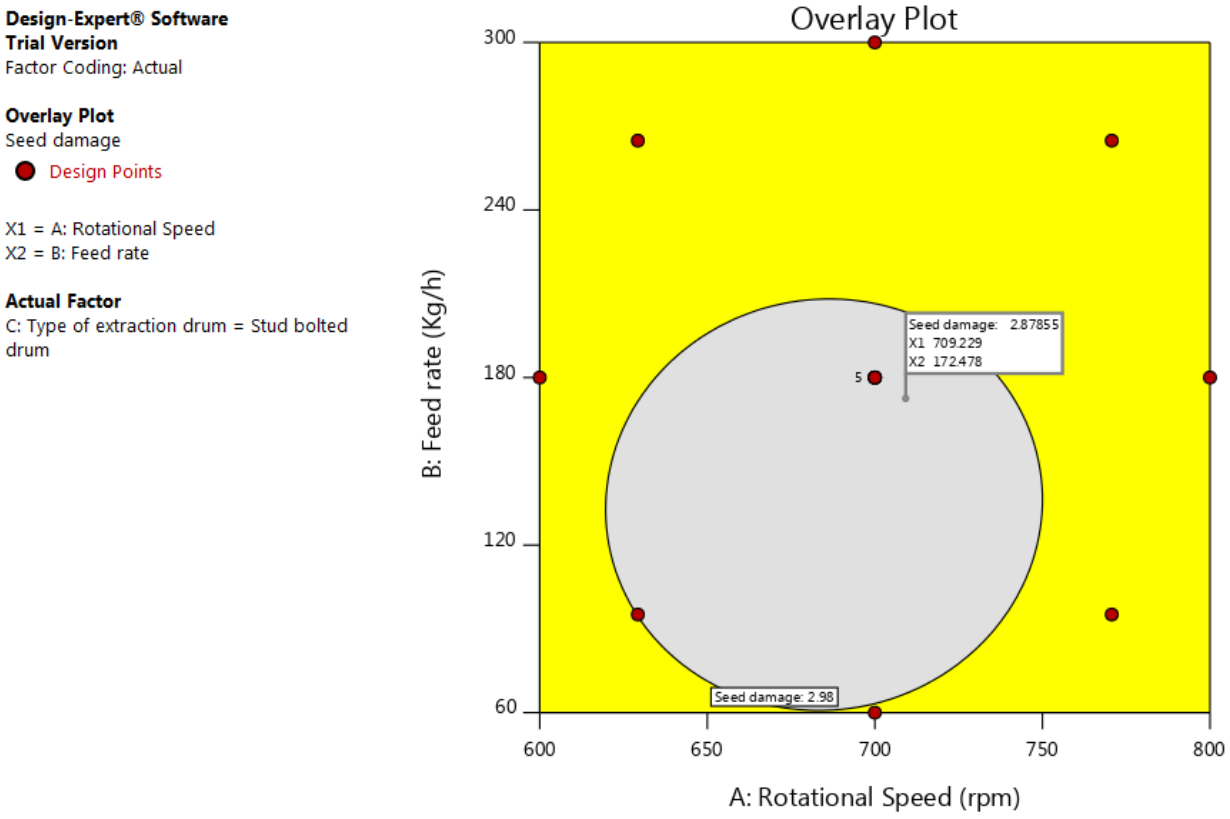

Fig 4 Superimposed contour plots for fennel seed damage

Verification of the model for fennel seed damage

Extraction of fennel seeds (sample size 2 kg) was carried out at optimized input parameters (Rotational speed = 709.22 ~ 700 rpm, Feed rate = 172.47 ~ 170 kg/h) for testing the adequacy of model equations for predicting the seed damage response values.

Table 4 Predicted and experimental values of response at optimum process conditions for fennel seed damage

Response	Predicted value	Experimental value	±SD
Seed damage, %	2.84	*2.97	±1.12

*Average of three replications

The observed experimental values (mean of three experiments) and values predicted by the equations of the model are presented in Table 4. The experimental values were found to be very close to the predicted values for mechanical seed damage. Therefore, it could be concluded from above discussion that model equation 2 is quite adequate to assess the behavior of mechanical seed damage during fennel seed extraction.

Germination

The germination percentage was significantly influenced by the cylinder speed. The highest germination of 91 per cent was observed for fennel seeds during extraction of fennel crops at optimized rotational speed and feed rate. The rotational speed affected the germination percentage significantly. It may be due to the fact that higher rotational speed above certain level resulted in higher rubbing forces than the requirement and higher feed rates above certain level at fixed concave clearance caused internal seed damage which resulted in decreased germination percentage. The results are in agreement with the researchers Bansal and Lohan (2009).

Conclusion

The optimized parameters for seed damage during fennel seed extraction were found to be stud bolted drum having rotational speed of 700 rpm and feed rate of 180 kg/h. The seed damage was found to be 2.84 per cent at optimized conditions.

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