Performance evaluation and optimization of solar operated plot thresher for chickpea seeds

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A study was conducted to optimize machine and operational parameters for the threshing of chickpea seeds using a portable solar-operated plot thresher. Experiments were conducted at different levels of independent parameters, viz. cylinder speed (8, 10, 12 m/s), concave clearance (10, 12, 14 mm) and concave grate clearance (8, 9, 10 mm). Dependent parameters such as threshing efficiency, cleaning efficiency, seed damage, threshing capacity, power consumption and seed germination were assessed. Face-centered central composite design was used for experimental design, result analysis and optimization using Design-Expert 11.1.0.1 software package. The optimized combination for threshing of chickpea seeds was found to be cylinder speed (10 m/s), concave clearance (14 mm) and concave grate clearance (9 mm).

Keywords: FCCCD, optimization, plot thresher, threshing.

CHICKPEA (*Cicer arietinum*) is a very nutritious pulse crop utilised for human consumption and animal feed. It ranks third in the importance list of food legumes cultivated throughout the world. It is mainly used as *Dal* in South Asia, while its hummus is broadly popular in numerous parts of the world. Chickpea is cultivated in more than 50 countries in the world. The global production of chickpeas in 2018 was 17.2 MT over 17.8 m ha of land. India is the largest producer of chickpeas, with production of 11.8 MT in 2018. Apart from India, Turkey, Iran, Mexico, Australia, Canada and Ethiopia are the other major chickpea-producing countries in the world[1]. In India, chickpea is cultivated mainly in rain-fed areas as they are well suited for its cultivation[2]. Madhya Pradesh is the leading state ranking first in both area and production of chickpeas contributing 34% in area and 41% in production in the country during 2017–18. Maharashtra and Rajasthan were next in terms of area[3]. Due to price hike, demand for legumes has increased[4]. There is a strong need to increase seed production of improved varieties to ensure the availability of high-quality seeds. More than 40% of the losses arise during post-harvesting and processing activities in developing nations[5]. Harvesting and threshing losses are the initial phases of post-harvest losses. The inability to accomplish these activities within the specified time may highly diminish the seed quality.

In chickpea production, there are some common operations at par with other pulse crops for which general machinery could be utilized with few changes/alterations. However, operations like harvesting and threshing have been facing issues because of the inaccessibility of combined harvesters and threshers[6]. Chickpea seed being dicotyledonous and the germ tip being located at the protruding structure makes it prone to mechanical injuries. Conventionally, research plots are threshed by manual beating or trampling under the hooves of animals or under tractor wheels which is labour-intensive, tiresome and time-consuming, as well as causes harm in the form of bruising of seed coat or splitting, resulting in low seed recovery and germination. A plot thresher is a small-capacity machine exceptionally designed to thresh trial plots at seed farms. This can be valuable in threshing individual plots with high precision and no seed damage. An experimental plot seed thresher was designed, developed and evaluated for wheat crops at the Central Institute of Agricultural Engineering research farm. In this thresher, threshing was done by the friction of the ear-heads of the crop between two rolling belts having corrugations[7]. As no special plot thresher was available for chickpea crops, a solar-operated plot thresher was designed and developed[8] based on the properties of chickpea seeds[9] at the Department of Farm Machinery and Power Engineering. Maharana Pratap University of Agriculture and Technology, Udaipur, India. The optimized operational and machine parameters varied for the threshing of different crops due to variations in their physical and mechanical properties. The drum speed was the most prominent in damaging seeds, followed by concave clearance and moisture content. These parameters had a significant effect on germination capacity[10]. Thus, the present study was conducted for performance evaluation and optimization of machine and operational parameters of the solar-operated plot thresher for the threshing of chickpea seeds.

Material and method

The designed plot thresher had a spike tooth threshing mechanism driven by a 750 W DC motor with 960 W solar panels. The experiments were conducted at Instructional

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Table 1. Experimental design and performance parameters obtained in the trials

Experiment no.	Cylinder speed (m/s)	Concave clearance (mm)	Concave grate clearance (mm)	Threshing efficiency (%)	Cleaning efficiency (%)	Seed damage (%)	Threshing capacity (kg/h)	Power consumption (kW)	Seed germination (%)
1	10	14	9	99.66	99.74	0.21	31.60	628.42	98.67
2	8	14	10	99.22	99.51	0.11	29.03	545.22	99.67
3	10	12	8	99.78	99.83	0.45	32.06	689.19	96.33
4	10	12	9	99.76	99.79	0.39	32.44	652.62	96.67
5	12	12	9	99.96	99.90	1.00	34.21	705.47	88.33
6	10	12	9	99.82	99.81	0.38	32.25	662.09	96.33
7	8	10	8	99.45	99.64	0.30	30.15	633.60	97.67
8	8	10	10	99.36	99.57	0.26	30.98	601.59	98.33
9	10	12	9	99.78	99.79	0.38	32.48	657.93	96.67
10	10	12	9	99.81	99.80	0.38	32.30	663.03	96.33
11	10	12	9	99.74	99.80	0.38	32.19	654.41	96.33
12	8	12	9	99.41	99.60	0.20	29.10	573.17	98.33
13	10	12	10	99.73	99.75	0.33	32.39	666.00	98.67
14	12	10	8	99.99	99.95	1.31	34.89	726.55	85.67
15	10	10	9	99.86	99.83	0.37	33.11	683.36	94.33
16	10	12	9	99.80	99.79	0.32	32.32	650.15	97.33
17	12	14	10	99.90	99.84	0.76	33.83	687.86	91.33
18	12	10	10	99.98	99.89	1.10	34.41	716.84	87.33
19	12	14	8	99.91	99.87	0.98	33.97	674.24	90.33
20	8	14	8	99.30	99.55	0.24	27.96	553.64	99.33
Mean				99.71	99.76	0.49	32.08	651.27	95.20

Farm, CTAE, Udaipur, for chickpea variety 'Pratap Chana – I' at the harvesting stage with different levels of cylinder speed (8, 10 and 12 m/s), concave clearance (10, 12 and 14 mm) and concave grate gap (8, 9 and 10 mm) as per the BIS test code (IS 6284–1985). The different levels of cylinder speed were obtained by changing pulleys, and concave clearance was adjusted by the mounting bolt. Three concaves of different grate clearance were fabricated.

Experimental design

In this study, a face centered central composite design (FCCCD) was implemented to investigate the relationship between independent and response variables for determining an appropriate experimental formulation. In FCCCD, $\pm\alpha = \pm 1$, which means the location of the star points is at the centre of each factorial space face. The number of experiments can be calculated by $(2^k + 2k + n)$, where k represents the number of independent variables, n is the number of centre points. The experimental design in this study required 20 experimental runs, which comprised 8 factorial points, 6 star points and 6 centre points at 3 experimental levels ($k = 3$, $n = 6$), as given in Table 1. The three independent variables were cylinder speed (X_1), concave clearance (X_2) and concave grate clearance (X_3).

Performance evaluation

The plot thresher was tested for chickpea crops as per BIS test codes (IS 6284–1985), and its performance was evaluated for different machine and operational parameters. No load test was carried out to determine the frictional horsepower of the solar-operated plot thresher for moving all components. During this test, the machine was run for about 10 min and visual observations and power consumption at no load were noted. A load test was carried out to check the performance of the thresher on the chickpea crop. All the experimental runs were conducted sequentially to complete 20 sets of combinations with the fixed feed rate of 2 kg per trial. For each run, the machine settings, like a change of concave clearance, concave grate clearance and cylinder speed, were done accordingly. The threshed chickpea seeds were collected from seed outlets, as shown in Figure 1.

Performance parameters, viz. threshing efficiency, cleaning efficiency, seed damage, threshing capacity, power consumption and seed germination, were determined as follows:

Threshing efficiency: This parameter was used to determine the threshing ability of the developed thresher. It is the ratio of the quantity of threshed seeds in the sample to the total quantity of seeds in the sample[11].

$$\text{Threshing efficiency (\%)} = \frac{G_{\text{th}}}{G_{\text{t}}} \times 100,$$

where G_{th} is the quantity of threshed seeds in sample (kg) and G_{t} is the total quantity of seeds in sample (kg).

Cleaning efficiency: It is the ratio of the weight of the seeds collected at the seed outlet to the weight of the total mixture of seed and chaff received at the seed outlet[11] and is expressed as

$$\text{Cleaning efficiency (\%)} = \frac{W_t - W_c}{W_t} \times 100,$$

where W_t is the weight of the total mixture of seed and chaff received at the grains outlet (kg) and W_c is the weight of the chaff at the seed outlet of the thresher (kg).

Seed damage: This parameter was used to determine the quantity of seeds damaged during threshing. It is the ratio of the quantity of damaged seeds collected in the sample to the total quantity of seeds in the sample[11], given as

$$\text{Seed damage (\%)} = \frac{G_d}{G_t} \times 100,$$

where G_d is the quantity of broken seeds in the sample (kg) and G_t is the total quantity of seeds in the sample (kg).

Threshing capacity: It is the capacity of the thresher in terms of the total quantity of threshed seeds in the sample per unit time. Threshing capacity[11] was calculated as

$$\text{Threshing capacity (kg/h)} = \frac{G}{T},$$

where G is the quantity of threshed seeds collected after threshing operation (kg) and T is the time taken to complete threshing operation (h).

Power consumption: A high-precision digital power analyser was used to determine the power consumption of the plot thresher.

Seed germination: The seed germination tests were conducted to find the germination percentage of threshed samples. From each threshed seed sample, a sample of 100 seeds was taken for a germination test. These seed samples were separately soaked in water overnight. Later, the seeds were placed in Petri dishes on moist germination paper, maintaining a gap among all seeds, as shown in Figure 2. The samples were observed daily for any contamination and germinated seeds. After 10 days, the number of germinated seeds was counted, and the average germination percentage was determined for each experiment.

Optimization of parameters

The mean values were calculated for all the parameters for each experiment. Design-Expert 11.1.0.1 software was used for statistical analysis. The results were used to generate regression models for optimizing the responses affected by independent factors. The trial data were fitted using the derived regression and selected models. The trial data were analysed graphically to illustrate the interaction between the dependent and independent variables. F-test was used to determine statistical significance. The parameters were optimized to maximize threshing efficiency, cleaning efficiency, seed germination with minimum seed damage and power consumption. The overlay plots were generated to obtain the optimized combination of the parameters.

Results and discussion

The performance parameters obtained at different combinations of independent parameters are given in Table 1. The response surface methodology quadratic model was found to be suitable for this purpose. The significance of different interactions observed from ANOVA is given in Table 2.

Effect of interactions of independent parameters on performance of the thresher

Threshing efficiency: Cylinder speed and concave clearance significantly influenced the threshing efficiency ($P < 0.001$).

Figure 1. Threshing of chickpea seeds using solar operated plot thresher.

Figure 2. Seed samples placed for germination.

Table 2. ANOVA for effect of independent parameters' interactions on performance parameters

Source	Threshing efficiency		Cleaning efficiency		Seed damage		Power consumption		Seed germination		Threshing capacity	
	F-value	*F*-value	*F*-value	*F*-value	*F*-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Model	129.41**	129.41**	309.10**	309.10**	241.37**	<0.0001	124.67**	<0.0001	152.97**	<0.0001	438.60**	<0.0001
X_1	1009.17**	1009.17**	2387.56**	2387.56**	1618.95**	<0.0001	860.57**	<0.0001	1033.05**	<0.0001	3455.94**	<0.0001
X_2	46.70**	46.70**	123.70**	123.70**	106.26**	<0.0001	175.39**	<0.0001	104.39**	<0.0001	305.46**	<0.0001
X_3	6.96*	6.96*	75.74**	75.74**	52.58**	<0.0001	8.41*	0.0158	14.68**	0.0033	15.62**	0.0027
X_1X_2	2.10^{NS}	2.10^{NS}	0.5263^{NS}	0.5263^{NS}	24.53**	0.0006	8.94*	0.0136	16.37**	0.0023	52.54**	<0.0001
X_1X_3	2.98^{NS}	2.98^{NS}	1.38^{NS}	1.38^{NS}	7.81*	0.0189	5.80*	0.0367	1.42^{NS}	0.2616	47.19**	<0.0001
X_2X_3	0.0046^{NS}	0.0046^{NS}	3.26^{NS}	3.26^{NS}	1.52^{NS}	0.2454	6.50*	0.0289	0.5095^{NS}	0.4917	2.52*	0.1432
$(X_1)^2$	29.32**	29.32**	61.14**	61.14**	188.57**	<0.0001	36.01**	0.0001	131.48**	<0.0001	50.57**	<0.0001
$(X_2)^2$	2.02^{NS}	2.02^{NS}	5.77^{NS}	5.77^{NS}	5.71*	0.0380	3.16^{NS}	0.1058	0.7439^{NS}	0.4086	3.21^{NS}	0.1035
$(X_3)^2$	1.76^{NS}	1.76^{NS}	1.24^{NS}	1.24^{NS}	7.12*	0.0235	14.08**	0.0038	6.18*	0.0322	0.0283^{NS}	0.8699
Lack of fit	0.9772^{NS}	0.9772^{NS}	2.86^{NS}	2.86^{NS}	2.46^{NS}	0.1726	2.13^{NS}	0.2132	2.23^{NS}	0.1997	1.72^{NS}	0.2840
Mean (%)	99.71		99.76		0.49		651.27		95.20		32.08	
Standard deviation	0.03		0.01		0.03		6.52		0.50		0.13	
Coefficient of variation (%)	0.03		0.01		6.45		1.0		0.52		0.40	

The concave grate clearance affected the threshing efficiency at a 5% level of significance. The interactional effect of independent parameters on threshing efficiency at 9 mm concave grate clearance is shown in Figure 3. Threshing efficiency increased with increased cylinder speed. At 12 mm of concave clearance, with increasing cylinder speed from 8 to 10 m/s, the threshing efficiency increased from 99.41% to 99.81%. Maximum threshing efficiency of 99.99% was observed at the highest cylinder peripheral speed of 12 m/s with the lowest concave clearances of 10 mm and concave grate 8 mm. At greater concave clearance and concave grate clearance, the pods fall out without separation of seed due to lack of required force exerted. Hence, the threshing efficiency decreases.

Cleaning efficiency: Cleaning efficiency was significantly affected by all independent parameters. The response surfaces for the interactional effect of independent parameters on cleaning efficiency at 9 mm concave grate clearance is shown in Figure 4. Cleaning efficiency was found to be proportional to cylinder speed and found to be in the range of 99.51–99.95%. At 12 mm of concave clearance, with increasing cylinder speed from 8 to 10 m/s, cleaning efficiency increased from 99.60% to 99.80%. The maximum cleaning efficiency of 99.95% was obtained at 12 m/s cylinder speed with concave and concave grate clearances of 10 and 8 mm respectively. At higher speeds and lesser clearances, crop material was finely chopped, and it was easy to be sucked up by the aspirator blower due to low terminal velocity, which thus resulted in higher cleaning efficiency.

Seed damage: Cylinder speed highly influenced seed damage. Figure 5 shows the effect of independent parameters on seed damage at 9 mm concave grate clearance. The seed damage increased significantly with increasing cylinder speed. From Figure 5, it was observed that at 12 mm of concave clearance, with increasing cylinder speed from 8 to 10 m/s, seed damage slowly increased from 0.20% to 0.38%, whereas with increasing cylinder speed from 10 to 12 m/s, seed damage increased vigorously from 0.38% to 1.0%. This was due to higher impact forces at high cylinder speeds. Seed damage decreased with increasing concave clearance and concave grate clearance.

Seed germination: The seed germination diminished significantly with increasing cylinder speed and increased with increasing concave clearance. The effect of independent parameters on seed germination at 9 mm concave grate clearance is shown in Figure 6. At 12 mm of concave clearance, with increasing cylinder speed from 8 to 12 m/s, seed germination decreased from 98.33% to 88.33%. Similarly, at 10 mm of concave grate clearance, with increasing cylinder speed from 8 to 12 m/s, seed germination decreased from 99.67% to 91.33%. The overall seed germination increased with increasing concave clearance and concave grate clearance.

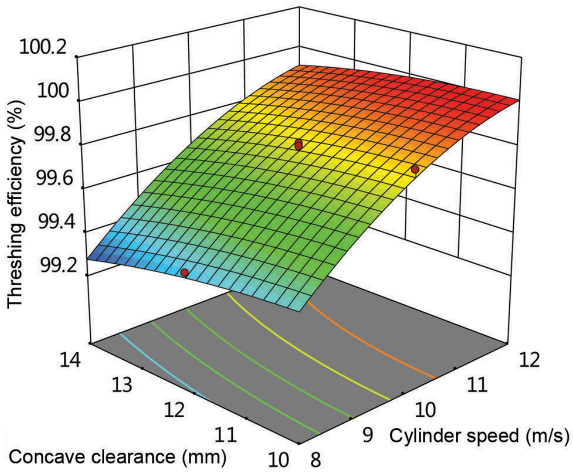

Figure 3. Interactional effect of independent parameters on threshing efficiency.

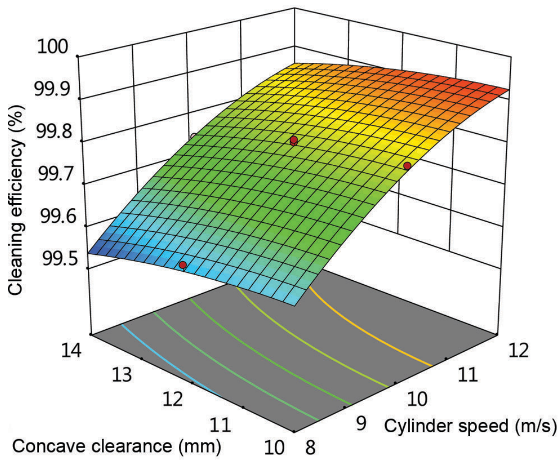

Figure 4. Interactional effect of independent parameters on cleaning efficiency.

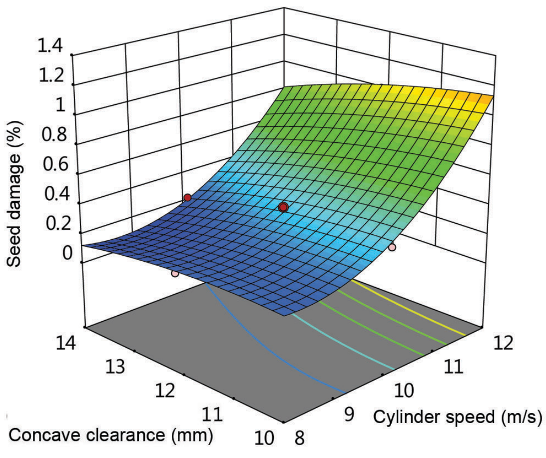

Figure 5. Interactional effect of independent parameters on seed damage.

Threshing capacity: The threshing capacity increased significantly with cylinder speed but decreased slightly with an increase in concave clearance. Figure 7 shows the interactional effect of independent parameters on threshing capacity.

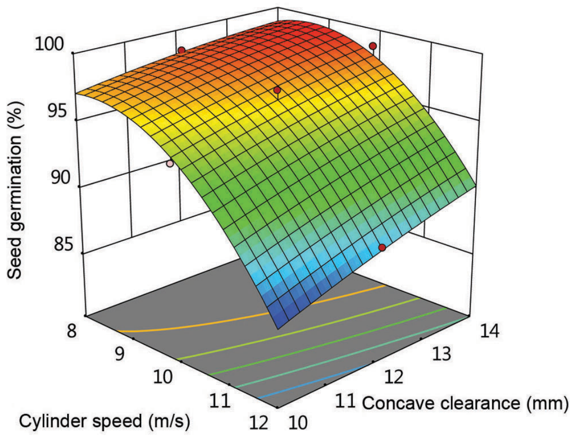

Figure 6. Interactional effect of independent parameters on seed germination.

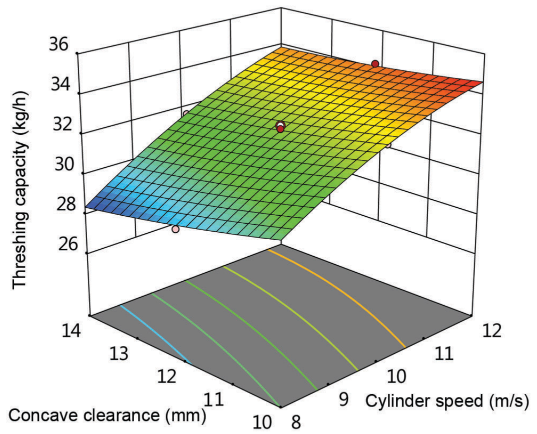

Figure 7. Interactional effect of independent parameters on threshing capacity.

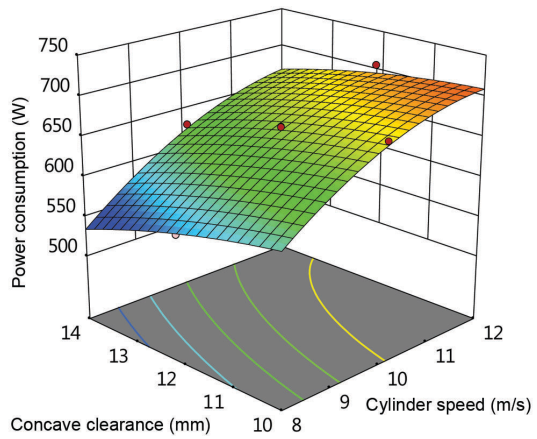

Figure 8. Interactional effect of independent parameters on power consumption.

As shown in Figure 7, threshing capacity increased from 29.10 to 34.20 kg/h with increasing cylinder speed from 8 to 12 m/s; moreover, the maximum threshing capacity of 34.88 kg/h was attained at the maximum cylinder speed (12 m/s) and minimum concave clearance of 10 mm. Similarly, threshing capacity increased with cylinder speed at all values of concave grate clearance. Increased feeding rate and seed separation at higher cylinder speed resulted in higher threshing capacity.

Power consumption: With increasing cylinder speed from 8 to 10 m/s, power consumption increased rapidly and thereafter, the rate of increase in power consumption with respect to cylinder speed was observed to be at a slower rate achieving maximum value. At 14 mm of concave clearance, with increasing cylinder speed from 8 to 12 m/s, power consumption increased from 545.22 to 687.86 W. Similarly, power consumption increased with cylinder speed at all values of concave grate clearance. The overall power consumption decreased with increasing concave clearance and concave grate clearance. The minimum power consumption was observed to be 545.22 W, and the maximum power consumption was 726.55 W. The effect of independent parameters on power consumption is shown in Figure 8.

Optimization of parameters for threshing of chickpea seed

From the present study, it was found that the cylinder speed and concave clearance highly influenced all the performance parameters, whereas concave grate clearance significantly affected cleaning efficiency, seed damage, seed germination and threshing capacity. A multi-factor graphical optimization technique was used to find the optimum workable

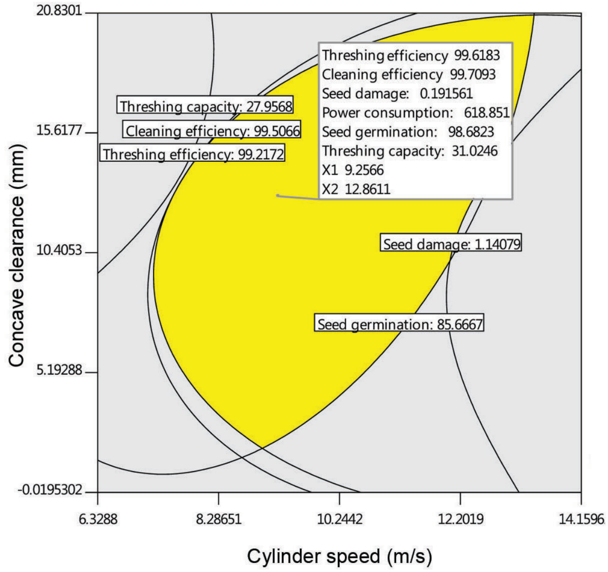

Figure 9. Overlay plot of cylinder speed and concave clearance.

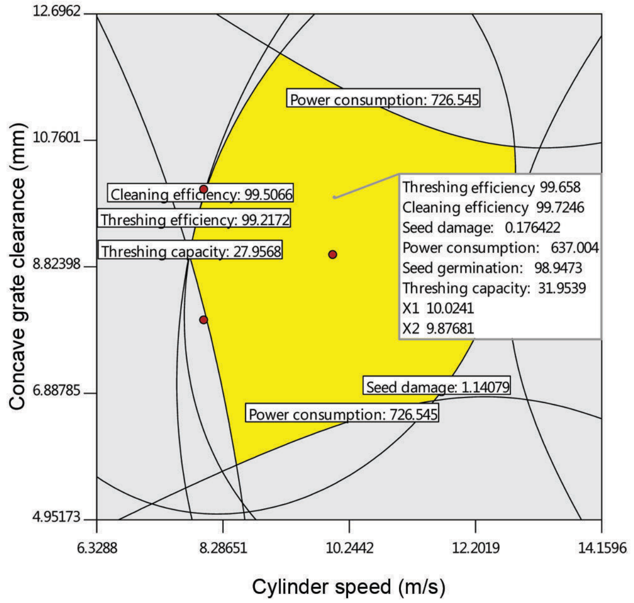

Figure 10. Overlay plot of cylinder speed and concave grate clearance.

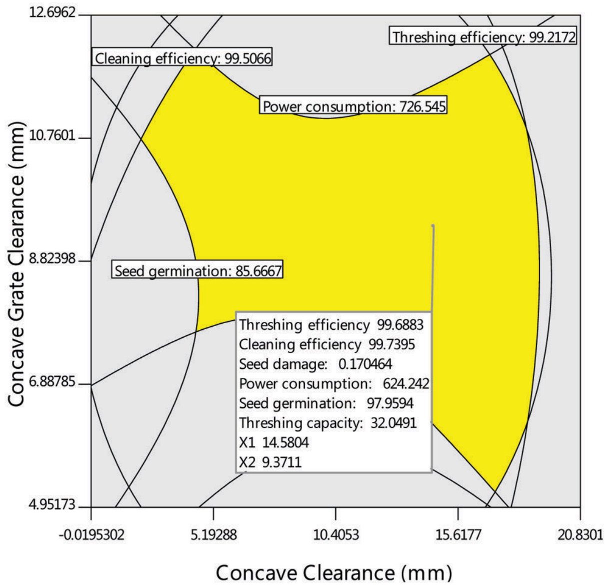

Figure 11. Overlay plot of concave clearance (mm) and concave grate clearance.

condition for the threshing chickpea crop. The contour plots, as shown in Figures 9–11, were superimposed for all independent parameters, and the yellow region shows the suitable combinations of the parameters for the best performance in the threshing of chickpeas.

Conclusion

The best performance of the plot thresher was observed at the following optimized combination of threshing parameters, viz. cylinder speed 10 m/s, concave clearance 14 mm and concave grate clearance 9 mm. At this combination, performance parameters were: Threshing efficiency 99.70%, cleaning efficiency 99.79%, seed damage 0.19% and seed germination 98.08%. The power consumption and threshing capacity were 625 W and 31.75 kg/h respectively. Thus, these optimized parameters will help in the mechanized threshing of chickpea seeds by the plot thresher, saving time and labour without causing seed damage.

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