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Optimization of Independent Parameters for Chickpea Threshing Using Response Surface Method (RSM)

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ABSTRACT

Kermanshah Province is the main producer of various chickpea cultivars in Iran. In this study, a laboratory peg-tooth thresher was employed for chickpea threshing. The effects of different cylinder speeds (9, 12, 15 m s^{-1}), concave clearance (12, 14, 16 mm), feed rate (80, 160, 240 kg h^{-1}) and seed moisture content (5, 10, 15% wb) were studied on percentage of grain damage, threshing efficiency, and percentage of germination. The experimental plan for optimization was prepared using response surface methodology technique with composite experimental design. The effects of all independent variables on the response variables were significant. The effect of cylinder speed was the most significant, followed by the moisture content. With increasing cylinder speed in the range of 9 to 15 m s^{-1}, the grain damage increased from 4.98 to 47.97%, threshing efficiency increased from 96.81 to 99.69%, and seed germination decreased from 85.75 to 55.98%. With increasing moisture content, grain damage and threshing efficiency decreased but seed germination increased. With increasing feed rate and concave clearance, grain damage and threshing efficiency decreased, while seed germination increased. The optimized point was determined at the cylinder speed of 10.63 m s^{-1}, concave clearance of 13.74 mm, feed rate of 240 kg h^{-1}, and moisture content of 12% (wb). In this condition, the optimum values of grain damage, threshing efficiency, and seed germination were 3, 98.3, and 84.29%, respectively.

Keywords: Germination, Grain damage, RSM, Thresher, Threshing efficiency.

INTRODUCTION

Kermanshah Province is the main producer of various chickpea cultivars in Iran. Chickpea cultivation area in the country is approximately 290,000 hectares and is mostly rain fed (Sarrafian, 2009). One of the most popular cultivars cultivated in Kermanshah is Bivanij. Size and quality of Bivanij cultivar is highly valued in the region (Tabatabaeefar *et al*., 2003).

Chickpea (*Cicer arietinum* L.) is one of the main human food and animal feed in south Asia and the third legume consumed in the world (Singh, 1988; Singh, 1990; Ziaulhaq *et al*., 2007). Its seed is a rich source of proteins and carbohydrates and the pod and seed coats are used as animal feed (Talebi *et al*., 2008). Chickpea is one of the most important edible legumes in Iran, which was reported as the main chickpea producer in the world in 2009, with 560,191 hectares of planting area and 208,913 tons of production (FAOSTAT, 2010).

Traditionally, chickpea crop is harvested manually and threshed with the machine. Thresher separates grain from pod and stalk by applying pressure and impact force. Due to the movement of the crop between stirring components of the thresher unit and

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improper clearance between the moving and stationery components, a notable damage occurs to the grains (Ukatu, 2006). Damaged grains pose less resistance against pests and diseases and have the minimum storage life. Grain grading plays a key role in determining the grain marketability and broken seeds reduce the grade of grain (Siska and Hurburgh, 1994; Wang *et al*., 1994). Additionally, broken grains impair germination ability (Spokas *et al*., 2008).

Grain threshing loss, grain damage, and mixed chaff with the grain are the most qualitative indices for evaluating thresher operation performance. Shpokas (2007) studied the design characteristics of a thresher apparatus and concluded that the feeding rate of materials into the threshing apparatus and technological parameters such as drum speed and clearance between the drum and concave had significant effect on the threshing performance. Moreover, Feiffer *et al*. (2001) reported that the crop cultivar, moisture, and biometrical indices also influenced the threshing process.

In another research, Petkevichius *et al*. (2008) considered four parameters including grain loss, grain damage, separation degree, and the ear length reduction as the quality indices for maize ear threshing. Results of this study showed that the clearance between drum rasp bars and concave and the drum peripheral velocity were two important factors in maize threshing process. Poničan *et al*. (2009) investigated threshing mechanism parameters of maize crop. They concluded that peripheral speed and clearance between cylinder and concaves were the most important factors affecting the crop quality. Their experiment results with the tangential threshing mechanism showed that with increasing the cylinder peripheral speed from 9.4 to 21.4 m s^{-1}, the grain damage increased from 3.8 to 6.01%. Sudajan *et al*. (2002) implemented different threshing units for sunflower seeds. They evaluated the thresher operation in terms of output capacity, threshing efficiency, grain damage, grain losses, separation, power requirement, and specific energy consumption using different drum types, drum speeds and feed rates and reported that visible grain damage increased with increasing drum speed and feed rate. Ajav and Adejumo (2005) evaluated an okra thresher with variable parameters such as concave clearance, seed moisture content, and cylinder speed. The results proved that germination of threshed seeds was significantly influenced by moisture content, cylinder speed, and concave clearance.

Vejasit and Salokhe (2004) studied machine-crop parameters of an axial flow thresher for soybean and reported that moisture content, feed rate, and threshing drum speed significantly affected the output capacity, threshing efficiency, grain damage, and grain losses during soybean threshing. The effect of drum speed, moisture content, and pod size was investigated on percentage of damaged grains and threshed pods in a finger type thresher for chickpea (Khazaei *et al*., 2003). Results indicated that the drum speed and pod size had the highest and lowest effects on the intensity of damage, respectively. Also, moisture content range of 12 to 18% with drum speed of 9.5 m s^{-1} was recommended as the best condition for chickpea threshing.

Although much information has been reported about the threshing of various agricultural crops such as cowpea (Ige, 1978), sunflower (Sudajan and Salokhea, 2002), okra (Ajav and Adejumo, 2005), soyabean (Ukatu, 2006), maize (Petkevichius *et al*., 2008), rice (Asli-Ardeh *et al.,* 2009), no study has been conducted about optimization of chickpea threshing using response surface methodology with respect to the machine-crop parameters. The main goal of this study was to optimize the technological parameters such as cylinder speed, concave clearance, feed rate, and moisture content using response surface method to obtain, the maximum threshing efficiency and seed germination and the minimum grain damage in threshing chickpea.

MATERIALS AND METHODS

Experimental Setup

Grain samples (Bivanij cv.) were taken from a local farm and were maintained in the farm to reach the desired moisture content, determined by the oven drying method at 103°C and 72 hours (ASAE, 2002). Average values of length, width, and thickness of the seed at 15% moisture content (wb) were 9.50, 7.27, and 7.21 mm, respectively.

After manual harvesting of chickpea, threshing operation was conducted using a laboratory peg-tooth type thresher. The fabricated thresher and its components are shown in Figure 1. The apparatus had a drum with 800 mm length and 18 teeth which were mounted on the four axes spaced at100 mm. The concave was made of perforated and rolled steel sheets with a diameter of 1,000 mm and length of 1,200 mm. The concave, which had a hole diameter of 10 mm, was installed on the frame using two flat steel bars. Plant material was fed through a funnel into the thresher. After threshing, the separated grains were fallen on the seed tray (screen) by gravity. Seed tray had oscillating motion and, at the end of the path, clean grain was obtained. The required power for the thresher was supplied by a three phase 2.3 kW electromotor. A set of V-belt and pulley arrangement was used to transmit the power to the thresher drum and other driven parts. Motor speed was controlled using an inverter (EDS1000-2S0037, China). Rotational speed of the cylinder was set at 478, 637 and 797 rpm to supply the linear speed of 9, 12 and 15 m s^{-1}, respectively.

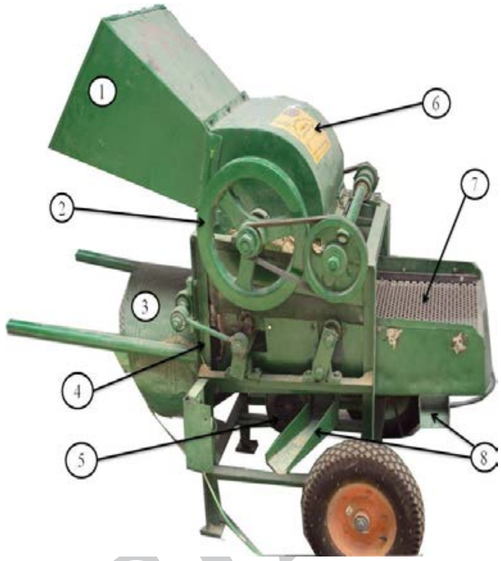

Figure 1. The chickpea thresher: (1) Funnel feed; (2) Flywheel; (3) Blower; (4) Main frame; (5) Electrical motor; (6) Threshing drum; (7) Screen, (8) Outlet for clean seeds.

Response Surface Method

Four independent variables of concave clearance (12, 14, 16 mm), cylinder speed (9, 12, 15 m s^{-1}), feed rate (80, 160, 240 kg h^{-1}) and moisture content (5, 10, 15% wb) were considered for optimization. The experimental plan for optimization included three dependent variables, namely, grain damage, threshing efficiency, and seed germination percentage. Thus, response surface methodology (RSM) with central composite experiment design (CCD) was employed to fit a second-order polynomial equation on the experimental data (Kathleen *et al*., 2004; Khuri and Mukhopadhyay, 2010). Levels selection of cylinder speed, concave clearance, and moisture content was made according to the limitations of the fabricated thresher and studies by other researchers (Klenin *et al*., 1986; Oplinger *et al*., 1990; Rani *et al*., 2001; Khazaei *et al*., 2003; Corp *et al*., 2004; Sinha *et al*., 2009). The independent variables were implemented at three levels in CCD-type experimental design and, finally, 30 experiments were conducted as shown in Table 1. The experiments were carried out in a random order. To calculate the sum of square error and the lack of fitness for the developed regression equation between the dependent and independent variables, six replications were performed at the central

Table 1. Design of experiments using central composite experiment design (CCD).

Experiment no.	Concave clearance	Cylinder speed	Feed rate	Moisture content
1	12	15	240	15
2	12	9	240	15
3	14	12	160	15
4	14	12	160	10
5	16	12	160	10
6	12	9	80	15
7	16	15	240	15
8	14	12	160	10
9	14	12	160	10
10	16	15	80	15
11	12	15	240	5
12	12	9	80	5
13	16	15	240	5
14	12	12	160	10
15	12	9	240	5
16	12	15	80	15
17	12	15	80	5
18	14	12	160	5
19	14	15	160	10
20	14	12	240	10
21	16	9	80	5
22	14	12	160	10
23	14	12	160	10
24	16	15	80	5
25	16	9	80	15
26	14	12	160	10
27	14	12	80	10
28	16	9	240	5
29	14	9	160	10
30	16	9	240	15

points of the coded variables (Myres, 2002). The Design-Expert software (version 7) was used for simultaneous optimization of the multiple responses.

Evaluation Procedure

The thresher was adjusted and installed on a hard surface and its performance was evaluated at three different levels of concave clearance, cylinder speeds, feed rate, and moisture content. The effect of these independent variables on grain damage, threshing efficiency, and germination was considered for the experiment. After turning on the thresher, samples were prepared randomly and fed to the thresher to attain the thresher performance indices. The following relationships were used to calculate responses (Ajav and Adejumo, 2005).

$$PCS = \frac{S_c}{S_{to}} \times 100 \quad (1)$$

$$PCS = \frac{S_u}{S_{to}} \times 100 \quad (2)$$

$$E_{th} = 100 - PUS \quad (3)$$

Where, PCS is percentage of cracked and broken seeds, s_c is the cracked and broken seeds from seed outlet of thresher (kg), s_{to} is the total seeds obtained from the thresher outlet (kg), PCS is the percentage of un-threshed seeds, s_u is the un-threshed seed obtained from all outlets of the thresher (kg), s_{to} is the total output grain (kg) and E_{th} is the threshing efficiency (%).

Germination test was carried out according to ISTA (1999) rules. Four replications of 100 seeds were placed between two layers of pre-wet germination papers in germinator and set at temperature of 20°C and relative humidity of 85% for eight days. The number of germinated seeds for each sample was finally counted. Percentage of germination was calculated as follows:

$$PG = \frac{S_g}{S_{tp}} \qquad (4)$$

Where, PG is the percentage of seed germination, s_g is the number of germinated seeds, and s_{tp} is the total number of planted seed.

RESULTS AND DISCUSSION

Grain Damage

Results of the variance analysis showed that the concave clearance, cylinder speed, feed rate, and moisture content had significant effect on the grain damage (Table 2). It was observed that the cylinder speed had the greatest effect followed by moisture content, feed rate, and concave clearance. Among the first-order interactions, the importance order was cylinder speed×moisture content, concave clearance×cylinder speed, cylinder speed×feed rate, and feed rate×moisture content. Figure 2-a shows the effect of cylinder speed and concave clearance on the percent grain damage. As can be seen in this figure, the grain damage increased with increasing the speed of threshing drum. At the concave clearance of 12 mm, when the drum speed increased from 9 to 15 m s^{-1}, the grain damage increased from 4.98 to 47.97%. At the concave clearance of 16 mm, increasing cylinder speed from 9 to 15 m s^{-1}increased the grain damage from 1.71 to 33.29%. This increase in damage was due to the higher impact levels applied to the crop during threshing. In contrast, with increasing concave clearance, grain damage decreased significantly.

The feed rate exhibited negative relation to grain damage across independent variables. Increase in feed rate from 80 to 240 kg h^{-1} at concave clearance of 14 mm reduced the grain damage by about 50% (Figure 2-b) since, at

Table 2. Analysis of variance for chickpea threshing using response surface quadratic model.

Source of variation	df [a]	*F*-value		
		Grain damage	Threshing efficiency	Germination
Model	14	164.62**	99.73**	100.50**
Concave clearance	1	70.63**	60.35**	42.18**
Cylinder speed	1	1437.46**	930.83**	1097.48**
Feed rate	1	78.75**	21.01**	35.56**
Moisture content	1	232.06**	144.55**	159.17**
Concave clearance×Cylinder speed	1	24.03**	35.36**	0.31ns
Concave clearance×Feed rate	1	0.83ns[b]	0.082ns	1.49ns
Concave clearance×Moisture content	1	3.59ns	0.78ns	0.44ns
Cylinder speed× Feed rate	1	15.69**	13.34**	0.019ns
Cylinder speed×Moisture content	1	94.68**	21.16**	5.62*
Feed rate×Moisture content	1	5.46*	0.92ns	0.016ns
$(\text{Concave clearance})^2$	1	1.45ns	0.090ns	0.090ns
$(\text{Cylinder speed})^2$	1	93.47**	52.46**	16.30**
$(\text{Feed rate})^2$	1	0.46ns	1.60ns	0.27ns
$(\text{Moisture content})^2$	1	5.38*	2.51ns	1.41ns
Residual	15			
Pure error	5			
Correlation total	29			

** Highly significant at 1% level; * Significant at 5% level; [a] Degrees of freedom, [b] Non-significant.

the lower feed rate, the crop received more intensive impact. Spokas *et al*. (2008) also reported that when feed rate decreased, the grain damage increased.

Figure 2-c shows that the grain damage percentage decreased significantly with increase in moisture content. On the other hand, with decreasing the moisture content from 15 to 5% at a cylinder speed of 15 m s^{-1}, the grain damage increased from 33.42 to 57.79%. The effect of moisture content on grain damage at lower cylinder speed was small. At the cylinder speed of 9 m s^{-1}, decreasing moisture content from 15 to 5% increased grain damage from 5.52 to 10.51%. Increasing grain moisture content increased the grain elastic behavior, therefore, cracking of the grain required more energy. A number of researchers have also reported moisture content as one of the major factors affecting the grain damage (Paulsen, 1978; Bartsch *et al*., 1986; Liu *et al*., 1990).

Threshing Efficiency

The experimental results indicated that the threshing efficiency was between 95.1 to 100% for the considered range of input variables (Figure 2- d to f). Results presented in Table 2 showed that the concave clearance, moisture content, cylinder speed, and feed rate had significant effects on the threshing efficiency at the 1% confidence level. Figure 2-d shows the effect of cylinder speed on threshing efficiency of chickpea. At the moisture content of 10%, with increasing cylinder speed from 9 to 12 m s^{-1}, threshing efficiency increased from 96.81 to 99.21%. Moreover, the maximum value of threshing efficiency (99.69%) was obtained at the maximum cylinder speed (15 m s^{-1}), which was expected.

Figure 2-e indicates that threshing efficiency decreased as concave clearance increased. With increasing concave clearance from 12 to 16 mm at the cylinder speed of 9 m s^{-1}, the threshing efficiency decreased from 97.45 to 96.16%. However, at the cylinder speed higher than 12 m s^{-1}, the effect of concave clearance was negligible. Higher threshing efficiency at the higher cylinder speed was due to increase in impact effect. The minimum threshing efficiency at the higher concave clearance was due to lack of required force exerted on pods and, therefore, pods fall out without seed separation. The interactions effects of cylinder speed and concave clearance on the threshing efficiency were significant at the 1% confidence level.

Threshing efficiency was negatively correlated with the feed rate Figure 2-f. When the feed rate increased from 80 to 240 kg h-1, the mean threshing efficiency decreased from 99.52 to 99.09%. This result showed that with increasing feed rate, the crop layer thickness between cylinder and concave increased; therefore, the effect of cylinder speed on the crop threshing decreased. Vejasit and Salokhe (2004) also stated that with increasing feed rate at all levels of drum speed, the threshing efficiency decreased.

Figure 2-f shows that the threshing efficiency significantly decreased with increasing input material moisture content. The maximum (99.52%) and minimum (98.31%) threshing efficiencies were related to the moisture contents of 5 and 15%, respectively. The effect of moisture content on threshing efficiency at the higher levels of moisture content was higher. Similar result was also reported by Rani *et al*. (2001). At the low seed moisture content, connecting force between seed and pod is low and pods are more brittle; therefore, seeds can be separated from pods easier. At higher moisture content, greater elasticity of plant materials caused increase in pod cohesion, therefore, threshing efficiency decreased. All interaction effects are presented in Table 2.

Seed Germination

The germination percentage of threshed chickpea seed was influenced significantly by cylinder speed, moisture content, feed rate, and concave clearance (Table 2). The germination of the threshed seed ranged

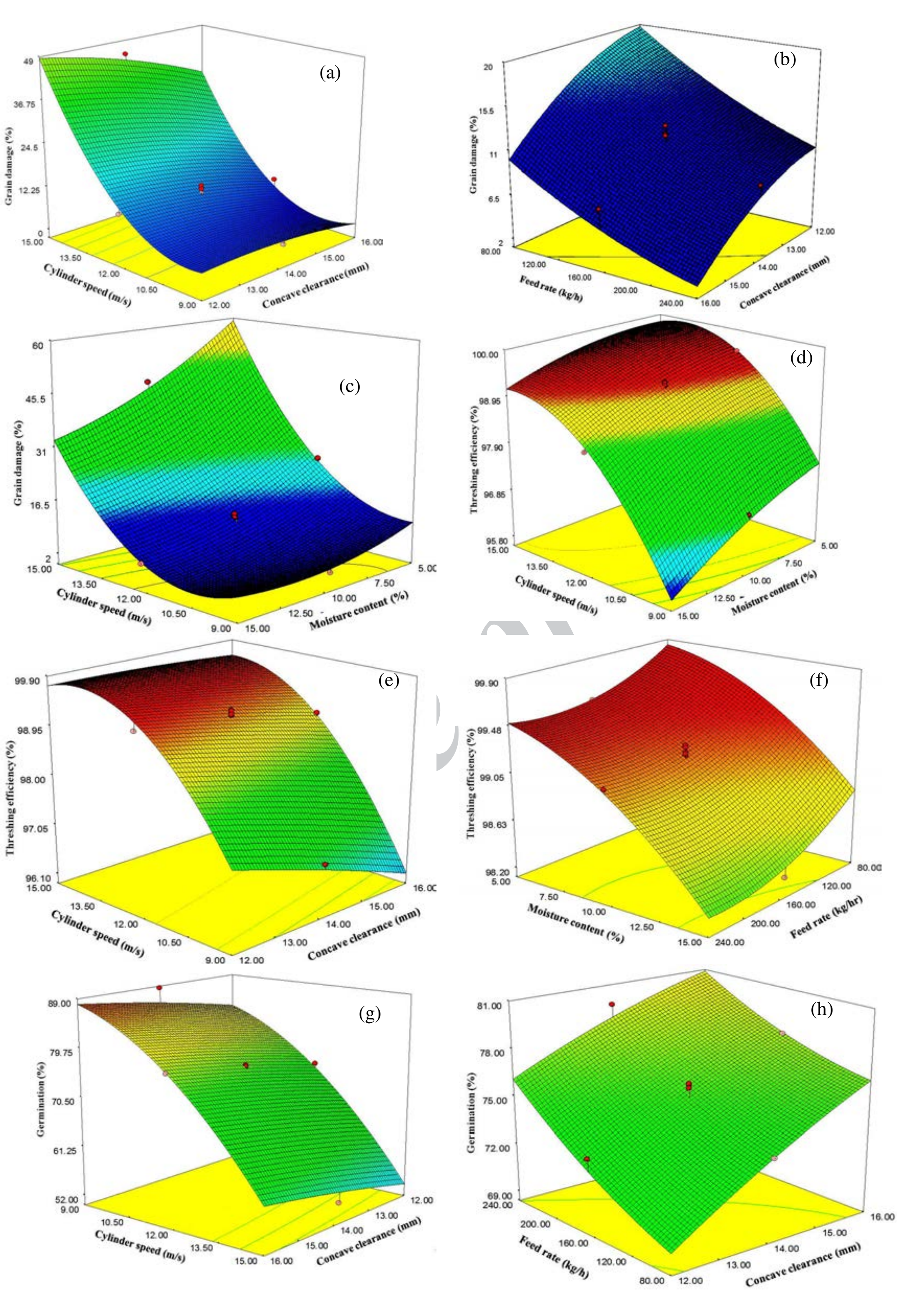

Figure 2. Effect of (a) cylinder speed and concave clearance, (b) feed rate and concave clearance, (c) cylinder speed and moisture content on grain damage percentage. Effect of (d) cylinder speed and moisture content (e) cylinder speed and concave clearance, (f) moisture content and feed rate, on threshing efficiency of chickpea. Effect of (g) cylinder speed and concave clearance (h) feed rate and concave clearance, (i) moisture content and cylinder speed on seed germination percentage. (Continued on next page)

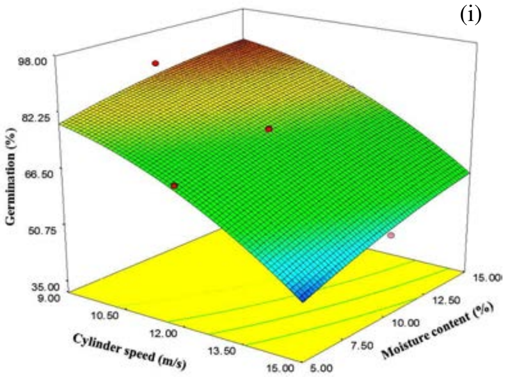

Figure 2. Continued.

from 39.18 to 96.60%. Cylinder speed was the most important factor affecting seed germination and moisture content, followed by concave clearance and feed rate. Figure 2-g shows that germination significantly decreased with increasing cylinder speed. When the cylinder speed increased from 9 to 15 m s^{-1}, seed germination percentage decreased from 85.75 to 55.98%. Many researchers have noted that this decrease was due to the increased damage to seed at the higher levels of cylinder speed (Ajav and Adejumo 2005; Rani *et al*., 2001; Sinha *et al*., 2009).

Variance analyses results showed that the effect of concave clearance on the percentage of seed germination was significant (P< 0.01). With increasing concave clearance from 12 to 16 mm, germination increased from 72.34 to 78.18%. Sinha *et al*. (2009) reported similar results about increasing chickpea seed germination with increasing concave clearance. Results of Ajav and Adejumo (2005) study also indicated that the minimum concave clearance caused the maximum reduction in seed germination.

Figure 2-h shows that increasing feed rate increased the seed germination. At the feed rate of 80 kg h^{-1}, germination was 73.58% and it increased to 78.94% when feed rate reached 240 kg h^{-1}. This was due to decreasing seed damage at the higher level of feed rate.

According to Table 2 and Figure 2-i, seed germination significantly increased as the moisture content increased. When moisture content increased from 5 to 15%, the mean value of seed germination increased from 68.57 to 79.91%. This was due to the reduction of impact and frictional rubbing force. Similar results have been reported for okra seed (Ajave and Adejumo, 2005). The interaction effects of moisture content and cylinder speed were significant on seed germination at the 5% confidence level. The maximum seed germination was 88.82%, which occurred at the cylinder speed of 9 m s^{-1} and moisture content of 15%.

Optimization of Chickpea Threshing Process

The optimum values and the graphical optimization are presented in Table 3 and Figure 3. These results are related to independent design parameters of the

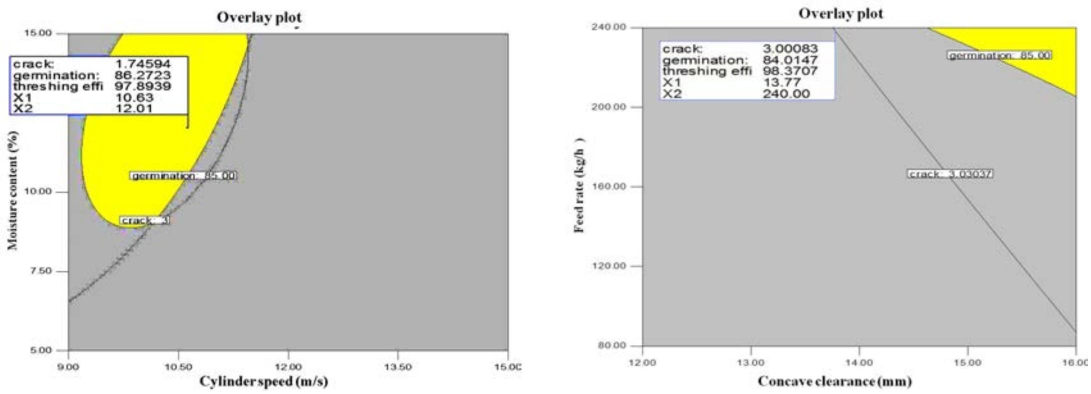

Figure 3. Superimposed contours for grain damage (%), threshing efficiency (%) and seed germination (%) at varying cylinder speed (m s^{-1}), moisture content (%), feed rate (kg h^{-1}), and concave clearance (mm).

machine to achieve the optimum values of grain damage, threshing efficiency, and seed germination. The desired targets (maximum or minimum) as well as the desired boundary for each independent variable and responses were selected according to the results of other researches and standards for thresher. Five optimum conditions of independent variables with the predicted values of responses generated using the software are presented in Table 3. The given values in the specified area in Figure 3 were grouped together and the optimized values of variables such as cylinder speed (10.63 m s^{-1}), concave clearance (13.74 mm), feed rate (240 kg h^{-1}), and moisture content (12%) were determined. Response values were grain damage (3%), threshing efficiency (98.3%), and seed germination (84.29%). The first computed value in Table 3 was found to be closer to the optimized values in the graphical optimization method. Accordingly, a threshing operation with cylinder speed of 10.63 m s^{-1}, concave clearance of 13.74 mm, feed rate of 240 kg h^{-1}, and moisture content of 12% (solution 1 in Table 3) was recommended for chickpea.

CONCLUSIONS

Cylinder speed, concave clearance, feed rate, and moisture content play an important role in threshed seed quality of chickpea and have a significant effect on grain damage, threshing efficiency, and seed germination. Among all the machine and crop parameters, cylinder speed was the most important, followed by moisture content. With increasing the cylinder speed from 9 to 15 m s^{-1}, the grain damage increased from 4.98 to 47.97%, threshing efficiency increased from 98.81 to 99.69%, and seed germination decreased from 85.75 to 55.98%. With increasing moisture content, the grain damage and threshing efficiency increased and seed germination decreased. Effect of concave clearance on the percentage of grain damage, threshing efficiency, and seed germination was significant ($P< 0.01$). In the feed rate range of 80 to 240 kg h^{-1}, the mean value of grain damage was between 16.65 and 7.67%, threshing efficiency varied from 99.52 to 99.09%, and seed germination increased from 73.58 to 78.94%.

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بهینه سازی پارامترهای مستقل برای کوبیدن نخود به کمک روش سطح پاسخ

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چکیده

استان کرمانشاه مهم ترین تولید کننده نخود در ایران است. در این تحقیق با ساخت یک کوبنده دندانه میخی اثر سرعت کوبنده (۹, ۱۲و ۱۵ متر بر ثانیه)، فاصله بین کوبنده و ضد کوبنده (۱۲, ۱۴ و ۱۶ میلی متر)، نرخ تغذیه (۸۰, ۱۶۰ و ۲۴۰ کیلوگرم در ساعت) و رطوبت محصول (۵, ۱۰ و ۱۵ درصد بر مبنای تر) بر روی درصد شکست دانه، بازده کوبش و درصد جوانه زنی بذرهای نخود مطالعه شد. نقشه آزمایش ها برای بهینه سازی با استفاده از روش سطح پاسخ و در قالب طرح مرکب مرکزی آماده شد. اثر همه متغیرهای مستقل روی متغیرهای پاسخ معنی دار بود. سرعت سیلندر و رطوبت، به ترتیب بیشترین تاثیر را بر روی متغیرها داشتند. با افزایش سرعت سیلندر در محدوده ۹ تا ۱۵ متربرثانیه، صدمات دانه از ۴/۹۸ به ۴۷/۹۸٪ ، بازده کوبش از ۹۶/۸۱ به ۹۹/۶۹٪ افزایش یافتند و درصد جوانه زنی از ۸۵/۷۵ به ۵۵/۹۸٪ کاهش یافت. با افزایش رطوبت محصول، صدمات دانه و بازده کوبش کاهش و درصد جوانه زنی افزایش یافت. نقاط بهینه در سرعت سیلندر ۱۰/۶۳ متربرثانیه، فاصله بین کوبنده و ضدکوبنده ۱۳/۷۴ میلی متر، نرخ تغذیه ۲۴۰کیلوگرم در ساعت و رطوبت محصول ۱۲٪ (بر مبنای تر) تعیین شد. مقادیر متغیرهای وابسته درصد شکست، بازده کوبش و درصد جوانه زنی در شرایط بهینه، به ترتیب برابر با ۳٪، ۹۸/۳٪ و ۸۴/۲۹٪ بدست آمد.