Development of a cleaner for threshed sunflower seeds using response system methodology

Esmaeil Chavoshgoli*, Shmsollah Abdollahpour, Hmidreza Ghasemzadeh

(Department of Biosystem Enginnering, Faculty of Agriculture, University of Tabriz, Islamic Republic of Iran)

Abstract: Nutty seed sunflowers are threshed at high moisture content. Various impurities are need to be removed before further processing. Cleaning unit including oscillation screens using kinematic equation and physical properties of seeds was designed, constructed and evaluated for separating impurities of threshing unit. RSM (response system methodology) modeling method is utilized for designing experiment and optimization of variable. The effects of oscillating frequency (7.6, 5.6, 3.6 Hz), slope (0.12, 0.07, 0.02) and amplitude oscillating (25, 17.5, 10 mm) of screens were studied. The results showed that the models were statistically significant at the 95% confidence level. It was observed that the amplitude oscillation on cleaning efficiency and screen slope on seed loss had the greatest effect followed by other factors. The maximum amount of cleaning efficiency was observed 93.98% at frequency 7.6 Hz, slope 0.12 and amplitude oscillation 25 mm. Also, the minimum amount of seed loss was reported 1.69% at frequency 5.6 Hz, slope 0.07 and amplitude oscillation 25 mm. Cleaning efficiency tended to increase with decreasing oscillations frequency while seed loss increased and then reduced insignificantly. With increasing in screen slope, cleaning efficiency increased and seed loss slightly decreased, and then increased. Increasing the oscillation amplitude caused the result that the cleaning efficiency reduced and seed loss increased and then decreased insignificantly. The optimum conditions for maximizing cleaning efficiency and minimizing seed loss were determined at oscillation frequency of 7.5 Hz, slope screen of 0.104 and oscillation amplitude of 25 mm.

Keywords: nutty seed sunflower, thresher, screen cleaner, RSM method

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1 Introduction

The nutty sunflower is usually cultivated on small farms and is threshed at about moisture content of 75% for separating of seeds from heads (Azharuddin et al., 2016; Mirzabe et al., 2014). The bulk of threshed heads includes hollow seeds, weed seeds, chaff material and inert material (Chavoshgoli et al., 2015). These contaminants must be removed and cleaned in the harvester machine for better storage and higher market price. In design of efficient and effective cleaning machines, physical properties of materials, kinematic parameters such as the amplitude of vibration and angular velocity of screens are taken into account (Mohsenin 1986; Myhan and Jachimczyk, 2016). Igbeka (1984) had observed that operational parameters and material related variables, screen oscillation speed, feed rate, screen slope, size of screen, perforated area, shape of opening, seed moisture content, stickiness and abrasiveness have significant effect on cleaning efficiency (Aradwad et al., 2018). In this regard, new cleaner unit structures have been designed by reasonably arranging the distribution of each component to improve the cleaning efficiency (Liu et al., 2015). Further cleaning is usually done using sieves to remove materials of other seed (MOG) from seed

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***Corresponding author: Esmaeil Chavoshgoli.** Department of Biosystem Enginnering, Faculty of Agriculture, University of Tabriz, Islamic Republic of Iran. Tel: +9809148422763, Email: esichavoshi@gmail.com.

(Awgichew, 2017). The objective of the present work was to develop and optimize a cleaning unit with mechanism of screens for a thresher of nutty sunflower seeds in Iran that would achieve high output capacity with appropriate variables to maximize cleaning efficiency whilst minimize losses seed. This work can be an important step at development of sunflower combine or harvester with high capacity.

2 Materials and methods

In this research, the nutty sunflower heads with locale name of GALAMI were procured from Experimental Orchard of university of Tabriz-Iran at moisture content of harvesting (Figure 1) .

Sunflower heads Sunflower grain Materials of other grain

Figure 1 Seed and materials of other seed (MOG)

Selected physical, mechanical and aerodynamic properties of the seeds and MOG, that are necessary for designing of cleaner unit, were obtained as the basic design data by the methods described and used by various researchers (Mohsenin, 1986; Chavoshgoli et al., 2015) (Table 1 and Table 2).

Table 1 Properties of nutty sunflower seeds

Property	Minimum	Maximum	Mean	Standard deviation
Length, mm	18.40	35.46	25.84	0.14
Width, mm	6.12	13.00	9.30	0.06
Thickness, mm	2.90	9.19	4.99	0.047
Equivalent diameter, mm	18.14	14.16	10.93	0.055
Sphericity, %	29.17	54.69	41.20	0.23
Mass, g	0.16	0.59	0.32	0.057
Project area, mm^2	91	239	137	0.29

Table 2 Properties of nutty sunflower seeds and MOG

Properties		Minimum	Maximum	Mean	Standard deviation
True density, kg m^{-3}	Seed	554	580	565	7.1
	MOG	802	831	822	4.31
Bulk density, kg m^{-3}	Seed	196	212	208	6.1
	MOG	81	99	89	3.08
Porosity, %	Seed	62.3	65.1	63.3	1.01
	MOG	88.76	89.81	89.12	0.53
Dynamic angle of repose	Seed	21.1	22.7	21.9	0.4
	MOG	25.20	28.10	27.01	0.71
Coefficient friction on steel surface	Seed	0.52	0.55	0.53	0.016
	MOG	0.68	0.71	0.70	0.021
Terminal velocity, ms^{-1}	Seed	6.57	9.82	8.10	0.71
	MOG	2.10	5.25	3.65	0.9
Drag coefficient	Seed	0.64	1.03	0.85	0.12
	MOG	0.44	1.22	0.78	0.21

In this study using equation kinematic and physical properties of seeds, a cleaner unit consists of screens developed and assembled to thresh unit of separator apparatus for nutty sunflower so that the variables of its components are adjustable for any condition and experiment (Figure 1). For designing of cleaner screens with definite frequency w (rpm) and amplitude of oscillation r (mm), kinematic index K was used (Iqbal, 2006). The parameters are suggested to follow K = 2.2 - 3, r = 23 - 30 mm and w = 200 - 350 rpm for effective cleaning.

$$K=\frac{rw^2}{g} \quad (1)$$

The screens were fixed inside the sieve assembly which is suspended by hangers and surface area of them obtained about 2.16 m^2 (length = 1.8 m and width = 1.2 m) according to the method of Mohsenin (1986). Screen must be placed at an angle (4º-8º) less than the angle of friction of the seed (Table 2) on the surface (Chavoshgoli, 2012).

The screen opening shape may be oblong, round, triangular. Material of more than 85% sphericity required round opening; less than 85% sphericity oblong opening and lense shaped material required triangular opening (Aradwad et al., 2018). The holes size using the geometric dimensions of the seeds on the screen was calculated as follows (Chavoshgoli, 2012):

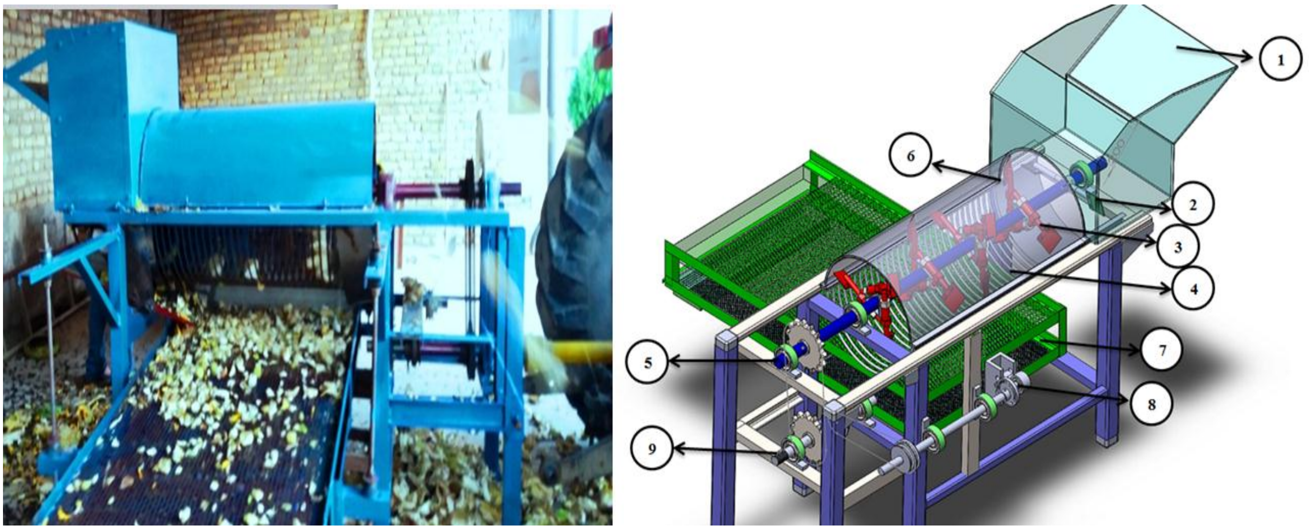
$$a_{\mathrm{c}} \geq M_{\mathrm{av}} + 3\sigma \quad (2)$$

Where is: a_c= the holes size (mm), Ma = average of geometric dimension, σ = standard deviation.

According to Sale et al. (2016) theoretical power required P_{cl} (kW) for oscillation approximated 1.6 kW by summation of power required for the movement in the vertical and horizontal directions.

$$P_{cl} = \frac{Ws \times w \times 2y}{4500} + \frac{Ws \times w \times 2\mu \times 2x}{4500} \quad (3)$$

Where, Ws = mass of screen with threshed material (N), μ = coefficient of friction of the moving component, x and y are horizontal and vertical displacement of screens (m) respectively.



(1) input channel, (2) feeder, (3) beaters, (4) separator (concave), (5) thresher shaft, (6) covering of drum thresher, cleaner unit: (7) set of screens, (8) crank of oscillation (9) power transmission

Figure 2 Schematic of the apparatus for separating sunflower seed, thresher unit

Tests were carried out on the screen cleaner to determine representative values of the operational parameters and performances under their different levels. The following performance indicators were used for the evaluation of cleaning unit (Chavoshgoli, 2012). The method to evaluate and optimize process parameters by conducting a series of experiments is very monotonous, time consuming and often very costly.

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j + \sum_{i=1}^{3} \beta_{ij} X_i \quad (4)$$

where, Y: predicted response, X_i and X_j are coded independent variables, β_0, β_{ii}, β_{ij} are regression coefficient.

It is necessary to have knowledge about the key input parameters that affect the part accuracy and quality before proceeding to conduct the experiment trials. In this study, the proposed experimental designed by the Response Surface Methodology (RSM) method in design expert software 11 with central composite experiment design (CCD) developed and the affecting parameters on accuracy will be analyzed and optimized (Tuyen et al., 2014). The quadratic model for prediction of responses was expressed using coded second order polynomial equation as follows (Bhushn et al., 2017).

Table 3 Experimental design proposed by RSM for screen cleaner

Run	A: Frequency (coded value)	B: Slope (coded value)	C:Amplitude (coded value)	Cleaning efficiency (%)	Seed loss (%)
1	3.6(−1)	0.07(0)	17.5(0)	91.00	2.01
2	5.6(0)	0.07(0)	17.5(0)	89.55	2.13
3	5.6(0)	0.07(0)	17.5(0)	91.75	2.19
4	5.6(0)	0.07(0)	25(+1)	91.87	1.69
5	5.6(0)	0.12(+1)	17.5(0)	93.23	2.52
6	7.6(+1)	0.12(+1)	25(+1)	93.98	1.89
7	5.6(0)	0.07(0)	17.5(0)	91.35	1.93
8	5.6(0)	0.07(0)	17.5(0)	91.34	2.11
9	3.6(−1)	0.12(+1)	25(+1)	93.35	2.33
10	3.6(−1)	0.12(+1)	10(−1)	92.16	2.46
11	3.6(−1)	0.02(−1)	25(+1)	92.98	1.76
12	5.6(0)	0.02(−1)	17.5(0)	89.67	2.39
13	7.6(+1)	0.07(0)	17.5(0)	89.15	1.99
14	7.6(+1)	0.02(−1)	10(−1)	88.06	2.01
15	3.6(−1)	0.02(−1)	10(−1)	90.06	1.99
16	7.6(+1)	0.12(+1)	10(−1)	88.43	2.56
17	5.6(0)	0.07(0)	10(−1)	88.12	1.98
18	5.6(0)	0.07(0)	17.5(0)	91.34	2.45
19	5.6(0)	0.07(0)	17.5(0)	88.15	2.57
20	7.6(+1)	0.02(−1)	25(+1)	91.01	1.83

The testing of the cleaning unit was carried out based on the slope of sieves (tanα (°)) atlevels of 0.12, 0.07, 0.02, frequency and amplitude of oscillation at levels of 7.6, 5.6, 3.6 Hz and 25, 17.5, 10 mm respectively in the stable feed rate 3000 kg (head) h^{-1} of threshing unit. Input parameters design factors and their measures are listed in Table 3. RSM appears to be an appropriate approach for analyzing and optimizing the process parameters. This process increases not only effectiveness but also product superiority (Salari et al., 2013; Baligidad et al., 2018).

3 Results and discussion

The significance of each factor was determined using the F-test and p-value as shown in Table 4.

Table 4 Analysis of variance for performance of sunflower cleaning unit using RSM

Source of variation	df	Cleaning Efficiency (%)		Seed loss (%)	
		F-value	p-value	F-value	*p*-value
Model	9	3.85	0.0236	3.72	0.0264
Frequency (A)	1	5.41	0.0426	5.40	0.0425
Slope (B)	1	5.97	0.0346	8.44	0.0157
Amplitude (C)	1	18.21	0.0016	4.75	0.050
AB	1	0.064	0.08049	0.0004	0.984
AC	1	1.64	0.2293	0.004	0.952
BC	1	0.064	0.8049	0.762	0.403
A^2	1	0.060	0.8105	0.394	0.544
B^2	1	2.67	0.1332	12.68	0.0051
C^2	1	0.127	0.7295	5.93	0.0351
Residual	10				
Lack of fit	5	0.457	0.7944	0.7446	0.623
Pure error	5				
Correlation total	19				

Note: P-values less than 0.05 indicate that they are significant at the 95% confidence level

The corresponding variables would be more significant if the absolute F-value becomes greater and the *p*-value becomes smaller (Safary and Chayjan, 2016). The results of analyses of variance which were summarized in Table 4 showed that the model was statistically significant at the 95% confidence level and demonstrated more individual factors that are statistically significant, whereas interaction factors were not effective. Statistical significance of the model, individual factors, their squares and interactions were estimated from their F- and *p*-values. It was observed that the amplitude oscillation on cleaning efficiency and screen slope on seed loss had the greatest effect followed by the other factors. The lack of fit was not significant relative to the pure error and meaning that the model was adequate for predicting performance of cleaner within the applied ranges of the process factors.

Response surface plots for cleaning efficiency and seed loss as a function of frequency, amplitude and slope of screen are presented in Figure 3. Maximum amount of cleaning efficiency was observed 93.98% at frequency 7.6 Hz, with slope 0.12 and amplitude oscillation 25 mm, as minimum efficiency was obtained 88.06% at frequency 7.6 Hz, slope 0.02 and amplitude oscillation 10 mm. Maximum amount of seed loss was observed 2.57% at frequency 5.6 Hz, with slope 0.07 and amplitude oscillation 17.5 mm. Also, minimum amount of seed loss was reported 1.69% at frequency 5.6 Hz, with slope 0.07 and amplitude oscillation 25 mm.

Cleaning efficiency tended to decrease with increasing frequency of oscillations while seed loss increased with increasing frequency at all amplitude and slope of screen (Figure 3 a, b and d, e). This result may be due to less resident time of materials to be separated on the screen. Higher sieve oscillations forced seeds and chaff to bounce without adequate time to reside on the screen so that the separation and cleaning to take place, hence poor or low level separation became eminent leading into low cleaning efficiency and high seed loss. Awgichew et al. (2017) and Voicu et al. (2007) concluded that high oscillation frequency lead, in general, to faster movement of seeds on the screen, so less time was available for the seeds to pass through materials on the sieve and sieve holes. They also indicated that at high frequency, seeds and chaff are discharged without passing through the sieves' perforations. Furthermore, it was learnt that sieves at high oscillation frequency could serve as conveyor rather than a means to sieve and sift through to effect separation.

As can be seen in Figure 3 (a, c and d, f) with increase in screen slope from 0.02 to 0.12, cleaning efficiency decreased insignificantly, and then increased and seed loss decreased to 1.69, and then increased to

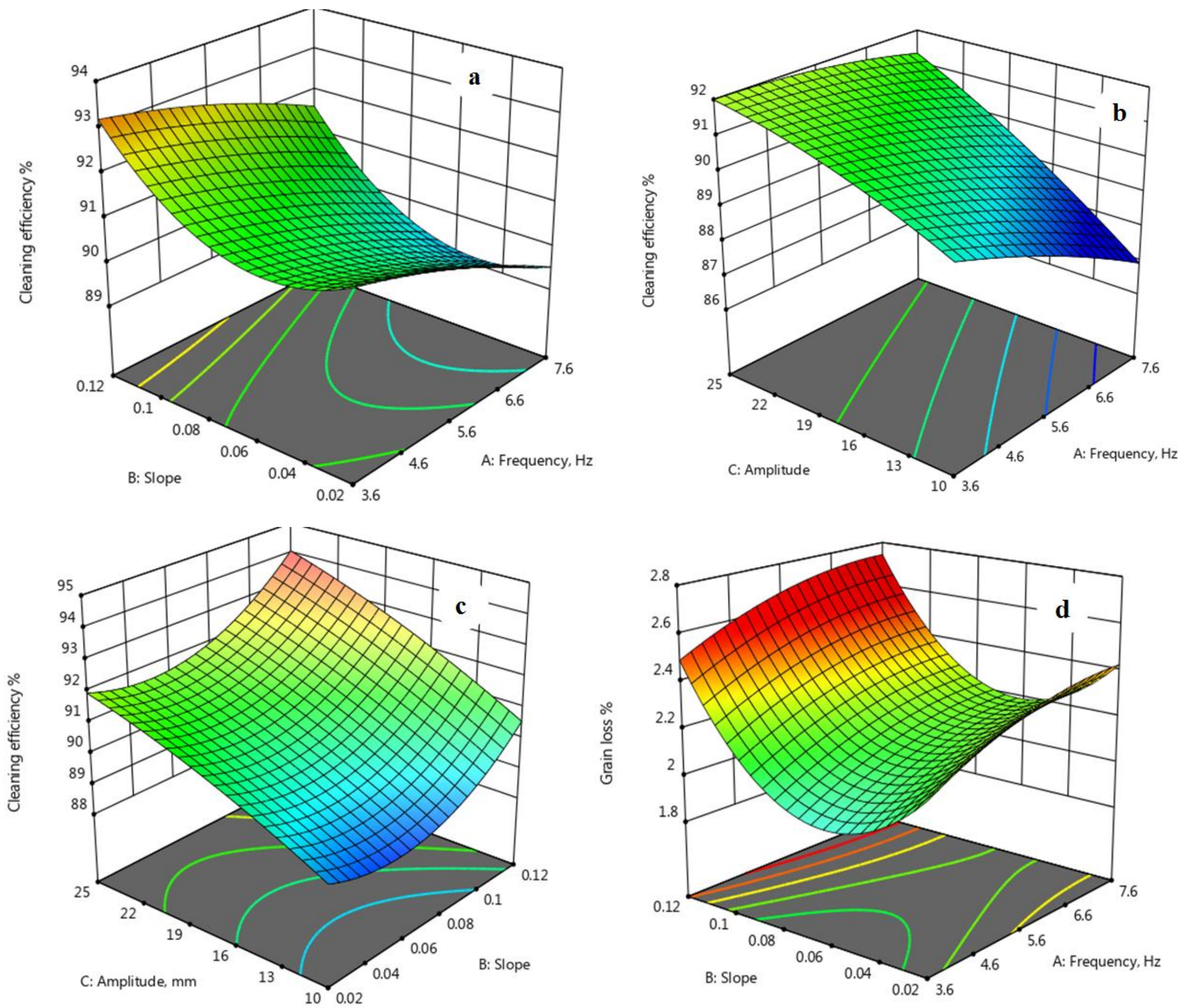
2.57 at all amplitude and frequency. This was due to the very fact that the seeds moved out of the separation unit they were with the MOG because of the greater force ($mg\sin\alpha$) acting on the entire material, seed and chaff, down the slope and the difference between gravity component and inertia component of forces that lead to sliding rather than tossing and flailing the seed and chaff. Awgichew et al. (2017) stated similar result for cleaning machine.

Figure 3 (b, c and e, f) indicated with increasing the amplitude oscillation of screens from 10 mm to 17.5 mm the cleaning efficiency increased and seed loss increased to 2.57 and then decreased to 1.69 at all frequency and slope of screen. As the interaction of the seeds and MOG rises, the seeds has further chance to pass through the holes screen at high amplitude. Myhan and Jachimczyk (2016) stated similar results in straw walker. But excessive amplitude oscillation increase is not recommended which causes seeds to be thrown on the screen surface rather than through the holes (Chavoshgoli, 2012).

The numerical presentation in variation of the cleaning efficiency and seed loss with different variables A = frequency of oscillation, B = slope of screen and C = amplitude of oscillation (Hz) was fitted well in polynomial Equation 5 and Equation 6 as given below:

$$\text{Cleaning efficiency (\%)} = 91.70063 - 0.658333A - 59.345B + 0.154744C + 1.0875A\times B + 0.036583A\times C + 0.29B\times C - 0.045A2 + 478B2 - 0.004622C2 \qquad (5)$$

$$\text{Seed loss (\%)} = -0.398775 + 0.460856A - 9.32955B + 0.195805C - 0.5375A\times B - 0.004083A\times C + 0.13B\times C\ 0.032614A2 + 129.81818B2 - 0.005253C2 \qquad (6)$$



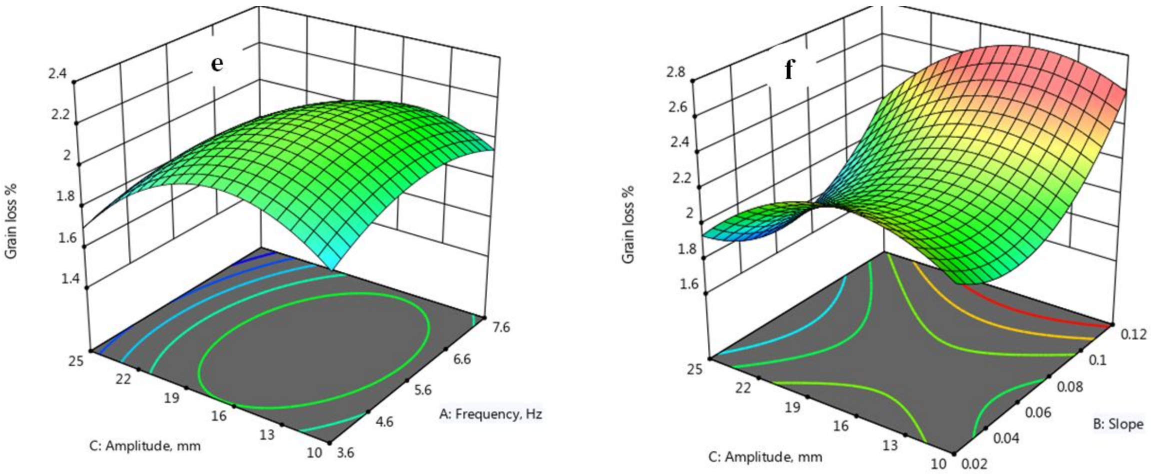


Figure 3 3D surface response plots to observed the effect of frequency, amplitude and slope of screens on cleaning efficiency (%) (a, b and c) and seed loss (%) (d, e and f).3.1 Optimization of process variables

Numerical optimization of independent variables was carried out by setting goals of maximization of cleaning efficiency and minimization of seed loss using RSM. Selection of optimum process conditions was based on model desirability. During optimization 77 solutions were obtained, out of which the most suitable criteria was selected. Similar study was also reported by Bhushn et al. (2017). The optimized values of variables such as oscillation frequency of 7.5 Hz, slope screen of 0.104 and oscillation amplitude of 25 mm were found suitable with higher desirability (0.86) function.

4 Conclusions

In this paper, cleaning unit including oscillation screen using properties of crops and kinematic equation was designed, constructed and assembled to a thresher of nutty sunflower for separating and cleaning of various impurities. Variables of its component are adjustable as well as the testing for any condition and development of machine harvesting. The Analysis of variance results showed that the models were statistically significant at the 95% confidence level. It was observed that the amplitude oscillation on cleaning efficiency and screen slope on seed loss had the greatest effect followed by other factors. With increasing the oscillation amplitude, cleaning efficiency increased and with increasing slope of screens, the seed loss decreased insignificantly and then increased. Maximum amount of cleaning efficiency was observed 93.98% at frequency 7.6 Hz, slope 0.12 and amplitude oscillation 25 mm. Also, minimum amount of seed loss was reported 1.69% at frequency 5.6 Hz, slope screen 0.07 and oscillation amplitude of 25 mm. The optimized points using RSM method for maximizing cleaning efficiency and minimizing seed loss were determined about at the oscillation frequency of 7.5 Hz, screen slope of 0.104 and oscillation amplitude of 25 mm.

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References

Aradwad, P., J. P. Sinha, T. V. A. Kumar, S. R. Yadav, and D. V. K. Sanuel. 2018. Development of solar powered screen cleaner. *Indian Journal of Agricultural Sciences*, 88(12): 1914–1923.

Awgichew, A. 2017. Performance evaluation of the seed and chaff separation and cleaning machine. *International Journal of Scientific and Research Publications*, 7 (7): 379-389.

Azharuddin, K., S. Mir, M. M. Narasimhan, and G. P. Kumar. 2016. Design and fabrication of sunflower seed extracting machine. *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, 5(6): 90–97.

Baligidad, S. M., U. Chandrasekhar, K. Elangovan, and S. Shankar. 2018. RSM Optimization of Parameters influencing Mechanical properties in Selective Inhibition Sintering. *Materials Today: Proceedings*, 5(2): 4903–4910.

Bhushn, B., I. Mani, A. Kar, and A. Datta. 2017. Optimization of jackfruit seed starch-soya protein isolate ratio and process variables for flaxseed oil encapsulation. *Indian Journal of Agricultural Sciences*, 87(12): 1657–1663.

Chavoshgoli, E. 2012. Determination of physical and aerodynamic properties of seed and MOG in order to design suitable mechanisms in separation and cleaning systems. M.S. thesis, Graduate Studies Office in Mechanic of Agricultural Machinery. Tabriz, Iran (in farsi).

Chavoshgoli, E., Sh. Abdollahpour, R. Abdi, and A. Babaie. 2015. Engineering properties of sunflower seeds and materials other seed as moisture content for equipment of separator. *Agricultural Engineering International: CIGR Journal*, 17(1): 10-21.

Igbeka, J. C. 1984. An appropriate technology cereal cleaner. *Agricultural Mechanization in Asia*, 15(2): 67–71.

Iqbal, M. 2006. Harvesting crops. Department of Farm Machinery & Power, University of Agriculture, Faisalabad.

Liu, Z., Y. Zheng, Z. Wang, D. Chen, and J. Wang. 2015. Design on air-flowing cleaning unit of micro rice-wheat combine harvester. *Transactions of the Chinese Society for Agricultural*, 46(7):102–108.

Mirzabe, A. H., G. R. Chegini, J. Khazaei, and J. Massah. 2014. Design, construction and evaluation of preliminarily machine for removing sunflower seeds from the head using air-jet impingement. *Agricultural Engineering International: the CIGR Journal*, 16(1): 294-302.

Mohsenin, N. N. 1986. Physical properties of plant and animal materials. *Gordon and Breach Science Publishers New York*.

Myhan, R., and E. Jachimczyk. 2016. Seed separation in a straw walker unit of a combine harvester. *Biosystems Engineering*,145: 93-107.

Safary, M., and R. A. Chayjan. 2016. Optimization of Almond Kernels Drying under Infrared-vacuum Condition with Microwave Pretreatment using Response Surface Method and Genetic Algorithm. *Journal of Agriculture Science and Technology*, 18: 1543-1556.

Salari, K., R. A. Chayjan, J. Khazaei, and J. A. Parian. 2013. Optimization of Independent Parameters for Chickpea Threshing Using Response Surface Method (RSM). *Journal of Agricultural Science and Technology*, 15(3): 467-477.

Sale, N. A., U. S. Muhammed, I. Dalha, and I. S. Idris. 2016. An improved IAR sorghum thresher. *Agricultural Engineering International: CIGR Journal*, 13(3): 119-126.

Tuyen, C. K., H. N. Minh, P. D. Roach, and E. S. Costas. 2014. Microencapsulation of gac oil by spray drying: Optimization of wall material concentration and oil load using response surface methodology. *Drying Technology: An International Journal*, 32(4): 385–397.

Voicu, G., T. Casandroiu, and L. Toma. 2007. Predictions regarding the Influence of the Material Movement Along the Sieve on Seeds Separation in Cleaning Systems from the Cereal Combine. *Proceedings of the 35th International Symposium Actual Tasks on Agricultural Engineering, Croatia*. 155-166.