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Development of solar powered screen cleaner

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ABSTRACT

Harvested grain mass contains various impurities that need to be removed before further processing. A solar powered screen cleaner was designed, fabricated and tested for separating impurities from soybean, lentil and chickpea grains. The machine consists of frame, feeding chute, screen cradle, discharge outlets, and drive unit. The angle of tilt of the sieve was varied between 3 and 8° while the hanger angle was maintained at 5°. Operating parameters such as screen cradle angle, oscillation and feed rate were optimized and the optimum performance was achieved at a screen cradle angle of 5^0, screen oscillation of 3.6 Hz, and feed rate of 150 kg/h.The slope of the sieve unit, cradle speed and stroke length could be adjusted easily. The developed unit was evaluated with 5 kg sample consisting of 80%, 85%, and 90% pure hand-cleaned grains mixed with 20%,15% and 10% impurities (chaff, stem, other crop seeds, weed seeds, clods, stones, etc.). The cleaning efficiency for whole chickpea, soybean and lentil was found to be 88.27%, 87.14% and 84.3%, respectively, and the losses observed was 2.12%, 1.25% and 1.73%, respectively. Overall machine efficiency was observed to be 83%.This machine assures good quality grain at affordable energy cost to small and marginal farmers in rural India.

Key words: Cereals and pulses, Cleaning and grading, Grain processing, Screen cleaner, Solar power

India is largest producer as well as consumer of pulses in world. As continuous transformative changes such as growing population and climate change pose new challenges for agriculture, by 2050, 1.3 billion mouths need to be fed with the same, rather depleting, amount of resources. One of the best ways to tackling this challenge is by reducing the post-harvest losses in foodgrains which accounts to 10% of the total production, which can feed one-third of India's poor and its monetary value, is about ₹/500 billion per year (FAO 2014).The bulk of harvested mass includes dead or broken seeds, weed seeds, inert material, and stones (Desai 2004, Schmidt 2007, Bishaw *et al.* 2007). These contaminants must be removed at theearliest for better storage and higher market price. These postharvest losses can be minimized significantly with primary processing (Sahay *et al.*2010). Cleaning and grading of agricultural commodities are considered as most important primary unit operations. In design of efficient and effective cleaning and grading machines, physical properties of materials are taken into account (Mohsenin 1986). At the same time the machines are designed keeping in mind certain requirements such as energy efficient possibility to adjust in a vast range of work parameters, and a low noise level (Reichert *et al.*1982).

Igbeka (1984) had observed that operational parameters and material related variables, viz. screen oscillation speed, feed rate, screen slope, pitch, size of screen, perforated area, shape of opening, seed bed depth, variety, moisture content, and degree of maturity, stickiness and abrasiveness have significantl effect on cleaning efficiency. Commercially available cleaning machines are mainly operated by grid power. However, grid power availability in rural areas is still erratic. In absence of grid power diesel power source is also dominant, but again the availability and cost of diesel is limiting. Furthermore, use of diesel also adds carbon dioxide to environment which is not environment friendly. Solar energy can be a good alternative and efficient energy source that can substitute the non-renewable energy sources with greater reliability. In some parts of country manually operated cleaning systems are also tried by farmers (Gosh *et al*. 1970). But continuous use of manual systems induces fatigue resulting in significant reduction in efficiency. Ultimately, marginal and small farmers do not go for proper cleaning of the harvested mass which becomes major cause for qualitative and quantitative loss during storage. No investigation has been done on adjustable screen mechanism suitable for multiple crops; screens are fixed in presently available cleaning and grading machines, which do not provide inter-operability for different grains. Low price, easy maintenance and usage, and technology appropriate for small and marginal farmers were key considerations in

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the development of the machine. In light of abosve facts, the present study was undertaken to design and develop a screen cleaning system with solar power.

MATERIALS AND METHODS

Popular varieties of soybean (DS-9814, DS-9712 and SL-688), chickpea (Kabuli, Pusa-112 and Pusa-72) and lentil (L-4549, L-4076 and Pusa Shivalik) were selected for the study. Raw material was procured from the Seed Production Unit, IARI and Division of Genetics, IARI, New Delhi. Selected physical properties of the grains,i.e. spatial dimension, size, sphericity, volume, bulk density, true density, angle of repose, static coefficient of friction and moisture content were determined by the methods described and used by various researchers (McCabe *et al.*1986, Mohsenin 1986, Dutta *et al.*1988, AOAC 1995).

Following factors were considered in the design of screen cleaner: 1. The screen opening shape may be oblong, round, triangular. Material of more than 85 percent sphericity required round opening; less than 85 percent sphericity oblong opening and lense shaped material required triangular opening. 2. Screen must be placed at an angle (4-8º) less than the angle of friction of the seed on the surface. 3. Screen cleaning machine must be inexpensive and made of local material and this machine must also be processing capacity of 100 kg/h uniform. 4. The stroke length of the screen also affects the separation efficiency. The optimum value of stroke length should be 7 mm for effective cleaning.

Physical properties of grains were obtained as the basic design data (Table 1). Design of the hopper was based on the flow characteristics of the grains. Experiments were carried out for determining the engineering properties of grains revealed that the flow characteristics like sphericity varied between 0.73-0.88 and angle of repose ranged between 25º - 30º at 10% (db) moisture. Therefore, the hopper was fastened at an angle of 35º for easy flow of the seeds. Average size of soybean was found about 5.5 mm and that of for chickpea was 6.7 mm. Mean size of lentil seed was found to be 4 mm. Hence, top screen for soybean, chickpea and lentil was selected as 8 mm, 10 mm and 5 mm, respectively.And the bottom screen for soybean, chickpea and lentil was selected as 4 mm, 6 mm and 2.1 mm, respectively (Table 1).The formulae used in the calculation of some of the parameters of various machine components are given in the equations 1 to 11 below (Khurmi 2001, Khurmi and Gupta 2006). The design values of tool geometry parameters of screen cleaner were determined based on the trials performed on existing machines. The data was analyzed to arrive at final design values. Pre modeling analysis was done using visual basic macro programming in "Microsoft Excel", "Working model 2005" and "Engineering power tools" software. Part modeling, assembly and drawings were prepared using CAD

Table 1 Physical parameters of selected soybean, chickpea and lentil at 10% MC (db)

Varieties	Length ± SE (mm)	Width ± SE (mm)	Thickness ± SE (mm)	Size ± SE (mm)	Angle of repose ± SE (0)	Static coefficient of friction on galvanized iron ± SE	Sphericity± SE	Bulk density ± SE (kg/m^3)	True density ± SE (kg/m^3)
Soybean varieties									
DS-9814	6.41 ± 0.41	5.77 ± 0.34	4.88 ± 0.36	5.62 ± 0.13	27.75 ± 1.70	0.30 ± 0.01	0.87 ± 0.13	715.52 ± 32.21	1116.3 ± 34.54
DS- 9712	6.34 ± 0.38	5.48 ± 0.36	4.71 ± 0.32	5.47 ± 0.21	26.32 ± 1.58	0.31 ± 0..03	0.86 ± 0.18	703.4 ± 29.87	1098.2 ± 32.12
SL-688	6.18 ± 0.34	5.44 ± 0.32	4.72 ± 0.38	5.41 ± 0.18	27.23 ± 1.34	0.31.5 ± 0.02	0.88 ± 0.20	711.33 ± 30.33	1097 ± 28.95
Chickpea varieties									
Kabuli	8.56 ± 0.55	6.41 ± 0.46	6.03 ± 0.82	6.91 ± 0.65	26.22 ± 0.94	0.41 ± 0.04	0.83 ± 0.43	715.4 ± 22.34	1184 ± 22.12
Pusa Nutan	7.85 ± 0.43	6.12 ± 0.38	5.82 ± 0.72	6.22 ± 0.44	29.50 ± 1.02	0.40 ± 0.03	0.84 ± 0.41	755.3 ± 23.43	1213.6 ± 19.4
Pusa- 72	8.22 ± 0.57	6.43 ± 0.43	5.52 ± 0.65	6.55 ± 0.54	30.1.12 ± 1.12	0.41 ± 0.05	0.82 ± 0.35	733.2± 19.8	1204 ± 16.32
Lentil varieties									
L-4076s	4.22 ± 0.21	4.10 ± 0.32	2.02 ± 0.15	3.29 ± 0.28	25.21 ± 1.19	0.39 ± 0.07	0.75 ± 0.23	768.43 ± 20.02	1277 ± 19.8
Pusa Shivalik	4.11 ± 0.21	4.02 ± 0.48	2.12 ± 0.12	3.35 ± 0.21	25.56 ± 1.32	0.40 ± 0.08	0.73 ± 0.18	776.2 ± 17.6	1231.1 ± 22.1
L-4549	4.19 ± 0.18	3.93 ± 0.28	2.17 ± 0.17	3.28 ± 0.18	27.32 ± 1.44	0.39 ± 0.02	0.76 ± 0.54	743.12 ± 18.5	1195.3 ± 20.7

software "solid works SP1". Based on these design values, a screen cleaner was designed and fabricated.

$$v = \frac{h}{3}(A1 + A2)\sqrt{A1 \times A2} \quad (1)$$

$$\tilde{A}_{max} = \frac{1}{2}\sqrt{\tilde{A}_b^2 + 4\tilde{A}_t^2} \quad (2)$$

$$\tilde{A}_b = \frac{32M}{\grave{A}d^3}, \tilde{A}_t = \frac{16T}{d^3\grave{A}} \quad (3)$$

$$D^3 = \frac{16}{\grave{A} \times T_s}\sqrt{(K_b \times M_b)^2 + (M_t \times K_t)^2} \quad (4)$$

$$\frac{N1}{N2} = \frac{D2}{D1} \quad (5)$$

$$P = T \times \omega, I \times \alpha \quad (6)$$

$$\acute{E} = \frac{2 \times \grave{A} \times n}{60} \quad (7)$$

$$L = 2C + 1.57(D_2 - D_1) + (D_2 - D_1)/4 \quad (8)$$

$$P_{th.output} = n \text{ x } A \text{ x } S_{ins} \text{ x}\text{Ŋ}_{mod} \quad (9)$$

$$\text{Ŋ} = \frac{P_m}{E \times A_c} \quad (10)$$

$$FF = \frac{P_m}{V_{oc} \times I_{sc}} \quad (11)$$

where, V= volume of hopper, m^2; A_1= area of top, m^2; A_2= area of base, m^2; h= height of hopper, σ_b = bending stress, σ_t = torsional stress, T_s= allowable shear stress for bending and torsion, N/mm^2; K_b = combined shock and fatigue factor applied to bending moment, N/mm^2; Kt= combined shock and fatigue factor applied to torsional moment, N/mm^2; M_b = maximum bending moment, N.mm; M_t = torsional/twisting moment, N.mm; N_1= speed of driven pulley, rpm; N_2 = speed of driving pulley, rpm; D_1 = Diameter of driven pulley, mm; D_2 = Diameter of driving pulley, mm; L = Length of belt, mm; C = Distance between driving and driven pulley, mm; n = number of PV modules; A=the module area, m^2; S_{Ins}= the total insolation, Wh/m^2/d; Ŋmod= the overall module efficiency, %; P_m= cells power output at its maximum power point, W; E= input light, W/m^2; A_c = surface area of solar cell, m^2; P_m = cellspower output at its maximum power point, W; V_{oc}= open circuit voltage, V; Isc = short circuit current, A.

The calculation showed that hopper capacity of 2.57×10^3 m^3 was appropriate for storage and feeding the material to the screen cleaner. The shaft diameter of 20 mm was found sufficient to overcome the pulley and eccentric unit load. The DC motor of 250 W operating at 24 V was found sufficient.

Based on the optimum operating condition determined and the requirements for proper cleaning mechanism; a prototype was first designed and machine components were fabricated and assembled. The cleaning machine consists of a frame, hopper, dual-screen assembly, eccentric unit and a dc motor. The eccentricunit with pitman and support linkagesimparted oscillation to the screen assembly during operation. The main frame was fabricated using mild steel angle iron (38 × 38× 4 mm) and braced to provide rigidity to mount and support all the other parts of the cleaner and to withstand vibrations during operation. The feeding chute of rectangular shape using the mild steel flat sheet of 2 mm thickness tapering down at the base mounted on screen cleaner. A slope of 35º from the horizontal at the bottom of hopper was provided for smooth flow of the seed material from hopper over scalping screen. Hopper fitted above a screen cradle and sliding type feeding arrangement was provided at the bottom the hopper. The screen cradle was tilted at about 5º to the horizontal and suspended by four bearings. The cradle had three outlets for discharging different fractions, viz. oversize, undersize and product. The 10 cm spacing kept between two screens.

Fig 1 Fabricated unit of solar powered screen cleaner.

The experimental setup consisted of a solar photovoltaic panel, DC motor and an experimental screen cleaner. The system consisted of 3 modules. The panel faced towards south. Three panels were connected in parallel to provide 250 W of secure power. The circuit voltage of each module at the point of peak power output is about 36.05 V and short circuit current is 7.85 A. The above values are specified at standard conditions (1000 W/m^2 solar radiation at 298.16 K and an air mass of 1.5).

Tests were carried out on the solar powered screen cleaner to determine representative values of the operational parameters and performances under their different levels. As per ISTA Rules the working sample is separated into three components, i.e. pure seeds, other seed, and inert matter. The percentage of each part is determined by weight. The working sample weight for purity analyses is calculated to contain at least 2500 seeds. Working sample of each seed soybean, lentil and chickpea 500 g, 60 g and 1000 g, respectively were taken to determine physical purity of seed on the weight basis. Amount of impurities, viz. other seeds and inert material, which had to be, separated manually. The test samples were prepared by adding 500 g, 750 g and 1000 g of impurities to pure seed of 4500 g, 4250 g and 4000 g respectively, to make a 5 kg size test sample for three crops for getting three levels of physical purity, i.e. 90, 85 and

80%. A 5 kg sample fed into the hopper and was cleaned. The weight of the impurities was taken before the cleaning operation commenced. With the aid of a stopwatch, time to accomplish cleaning for batches of different samples was recorded successively. Samples were collected from three different outlets and measured accordingly. Data for the corresponding experiments were recorded. Deductions for the values of the cleaning efficiency, cleaning loss and the throughput of the machine were made. The experimental design for the research was factorial randomized block design. A factorial randomized block design allows studying the effect of each factor on the response variable, as well as the effects of interaction between factors on the response variable.The effect of grains (Soybean, chickpea and lentil) and physical purity levels (80, 85 and 90%) on cleaning efficiency was shown by ANOVA.

RESULTS AND DISCUSSION

Effect of purity level on cleaning efficiency for soybean, chickpea and lentil

For soybean grains the average cleaning efficiency was 81.69% at 80% physical purity, for 85% physical purity the average cleaning efficiency was 85.56%, whereas at 90% physical purity the cleaning efficiency was 87.14%. Similarly for chickpea the average cleaning efficiency observed were 81.26%, 83% and 88.27% at three physical purity levels 80%, 85% and 90% respectively. For lentil average cleaning efficiency were 80%, 83% and 84.3% at physical purity levels of 80%, 85% and 90% respectively. Similar results reported by Tabatabaeefar *et al.* (2003). It shows that crop types has no significant effect on cleaning efficiency but the physical purity has significant effect at 5% level of significance (Table 2). It was observed that cleaning efficiency had linear relationship with the physical purity.

Table 2 Operational parameters of the screen cleaner

Performance parameter	Formulae
Cleaning efficiency calculated : (IS 5187:1980)	Cleaning Efficiency(%) = {E(F-G)(E-F)(1-G)}/{F(E-G)^2(1-F)} Where, E= Fraction of clean seed at clean seed outlet, %; F = Fraction of clean seed in feed, %; G= Fraction of clean seed at foreign matter outlet, %
Losses: Werby (2009)	Losses (%) = Weight of seed at the chaff outlet/ Weight of seed at input Total losses = (Seed lost behind the machine / Seed output) × 100
Specific energy consumptions	Specific power consumed = {(f − i) d× 3600}/(t × F × E) Where, P: the power consumption, Kwh/kg, f: final energy meter reading, kw; i: initial energy meter reading, kw t: time for cleaning the sample, sec, F: feed rate, kg/h, E: cleaning efficiency

Table 3 F value for the result of the performance tests

Source of variation	Degrees of freedom (DF)	Sum of squares (SS)	Mean squares (MS)	F value	Pr>F
Cleaning efficiency					
Crop *type* (CP)	2	17.08	8.54	2.12	0.1519
Physical purity (PP)	2	126.99	63.49	15.80	0.0002
Interaction					
CP*PP	4	20.90	5.22	1.30	0.3117
Cleaning losses					
Crop type (CP)	2	1.534	0.7671	4.86	0.0225
Physical purity (PP)	2	14.13	7.069	44.76	<0.0001
Interaction					
CP*PP	4	0.7622	0.1905	1.21	0.3464
Specific power consumption					
Crop type (CP)	2	1.10E-8	5.53E-9	2.35	0.1274
Physical purity (PP)	2	1.07E-7	5.37E-8	22.85	<0.0001
Interaction					
CP*PP	4	1.99E-9	4.98E-10	0.21	0.9281

*Significance (P=0.05)

Effect of purity level on losses for soybean, chickpea and lentil

For soybean seeds the average losses was 3.401% at 80% physical purity, for 85% physical purity the average losses were 2% whereas at 90% physical purity the losses were 1.25%. Similarly, for chickpea the average losses observed were 3.4%, 2.82% and 2.12% at three physical purity levels 80%, 85% and 90%, respectively. For lentil, average losses were 3.6%, 2.36% and 1.73% at physical purity levels of 80%, 85% and 90%, respectively. The crop types and physical purity has significant effect on losses at 5% level of significance (Table 2). The obtained results are

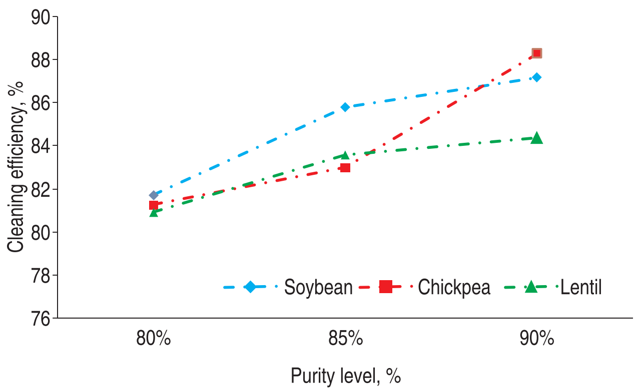

Fig 2 Effect of purity level on cleaning efficiency for soybean, chickpea, lentil.

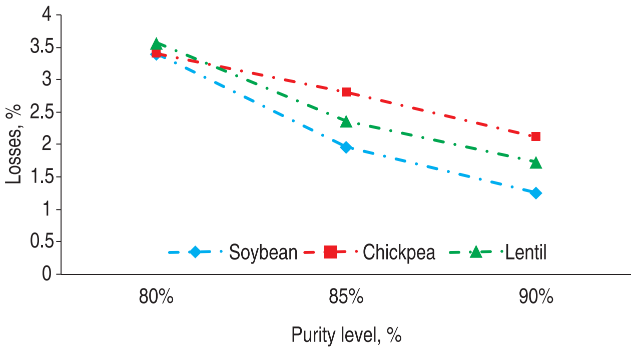

Fig 3 Effect of purity level on losses for soybean, chickpea, lentil.

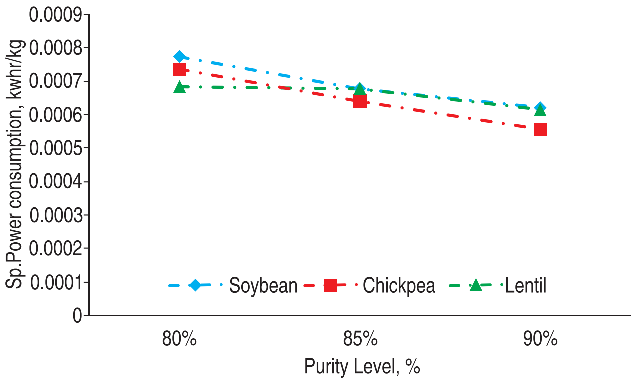

Fig 4 Effect of purity level on specific energy consumption for soybean, chickpea and lentil.

complying with the losses reported (Muhammad *et al.*2013). The results shown that as the physical purity increased, losses were decreased (Fig 3).

Effect of purity level on specific power consumption for soybean, chickpea and lentil

Effect of three crop levels and three levels of physical purities on the specific power consumption was studied. It was found that there was no effect of crop on specific power consumption, however; the physical purity had significant effect on specific energy consumption (Table 2). Lower physical purity consumed higher specific energy during cleaning operation (Fig 4).

Conclusion

Multi-grain cleaner with capacity 150 kg/hr was designed, fabricated and tested. This solar operated machine reduces the cost of operation as well as emission of greenhouse gases. The designed flexible cradle will help in accommodating different types of screens for various types of grains. The performance evaluation was conducted and the results of the study showed that for different grains at different levels of purity, cleaning efficiency was found in the range of 80-90%. Loss of quality grain in different foreign material outlet was significantly reduced. Multi-grain processibility, higher cleaning efficiency and less energy consumption makes this machine technologically appropriate for small and marginal farmers. This machine meets the demands of quality seeds/grains and helps in improving the income of rural farmers with an efficient cleaning machine running on assured power source.

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