PERFORMANCE EVALUATION OF TEF GRAIN AND CHAFF SEPARATION AND CLEANING MACHINE

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Abstract: The performance of the machine was evaluated in terms of separation and cleaning efficiencies, and separation and cleaning losses at different feed rate, sieves oscillations and sieves inclinations; three levels of sieve slopes (0, 5 and 10 degrees), four levels of sieve oscillation (5, 10, 15 and 20 Hz) and four levels of feed rates (3, 6, 9 and 12 kg/min) were used. The experimental design was factorial in split-split plot. The prototype tef grain separating and cleaning machine had the ability to winnow the premature grains, chaff and leaves, which are lighter than grains. It was also capable of reducing time wastage, grains loss, labour requirement and contamination. The performance evaluated in terms of separating efficiency, cleaning efficiency, separation loss and cleaning loss at different sieve slopes, sieve oscillations and feed rates indicate that the separation and cleaning losses increased with increasing sieve oscillation and feed rate for all sieve slopes. But the separation and cleaning efficiencies decreased with increasing sieve oscillations and feed rates at all sieve slopes. The minimum losses and the maximum efficiency were achieved at 5o sieve slope for all sieve oscillations and feed rates. The separation efficiency, cleaning efficiency, separation loss and cleaning loss were 97.94, 98.58, 0.71 and 0.7%, respectively at sieve oscillation of 5 Hz, feed rate of 3 kg/min and sieve slope of 5 degrees. The separation efficiency, cleaning efficiency, separation loss and cleaning loss were 52.71, 39.88, 25.62 and 34.5%, respectively, at sieve oscillation of 20 Hz, at feed rate 12 kg/min and at sieve slope of 5 degree.

Key words: Tef separation and cleaning, sieve slope, Sieve oscillation, feed rate, efficiencies, and losses.

Nomenclature

FR-feed rate
Hz - Hertz
Kg – kilogram
Min – minute
MOG – materials other than grain
SO – Sieve oscillation
SS – Sieve slope

1. Introduction

One of the economical cereal crops in Ethiopia is tef. It is indigenous to the country, and is a fundamental part of the culture, tradition, and food security of the people (Abayineh and Abebe, 2015). Currently, tef is grown on approximately 2.80 million hectares of land which is 27% of the land area under cereal production. Tef accounts for about a quarter of the total cereal production and is highly economical food grain in Ethiopia (Bekabil *et al.*, 2011). The traditional methods of postharvest handling of tef usually lead into contamination of the product with stones, sticks, chaff, dirt and dust. Therefore tef grain, after threshing cannot be stored or used for consumption or as planting material due to the very fact that the presence of long straws, chaff, small fragments of spikes, leaves, dust, dirt and other foreign materials in the grain will accelerate deterioration, thus lead to poor physical condition. Tef winnowing, separation and cleaning i.e. removal of undesirable materials, is accomplished manually by tossing the grain into air and letting the wind do the separation and cleaning, removal of lightest impurities, leaves

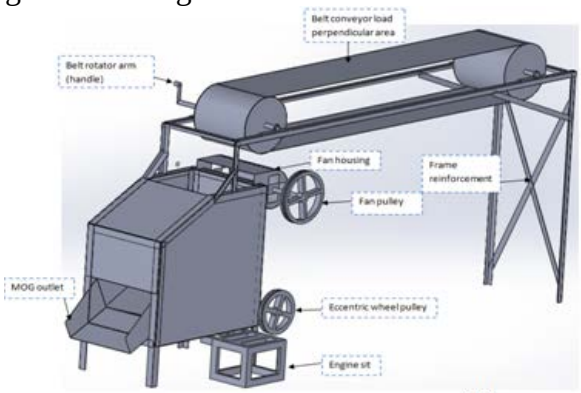
and large amount of debris with certain amount of grains. For further cleaning is usually done using sieves to remove the heavy particles and dirt larger than that of tef grain. Against all the odds, the Ethiopian farmers prefer to grow tef because it tolerance to low moisture stress, waterlogged and anoxic conditions being better than maize, wheat, and sorghum. Cattle prefer to feed on tef straw rather than any other cereal straws. Moreover, tef as grain has highest market prices than the other cereals; this includes both grain and straw, and the grain is not attacked by weevils during storage (Seyfu, 1993).

2. Material and method

This work was carried out in 2015 season, in order to study some parameters affecting separating and cleaning unit such as diameter of holes, air speed, sieve tilt angle, and sieve oscillation.

2.1. Machine specifications and description:

In the investigation, the machine used for tef chaff and grain separating and cleaning, was constructed and tested. The machine followed the design of (**Abayineh and Abebe, 2015).**The portable seed cleaner was developed to fill the need for a faster and more efficient method of tef grain and chaff separating and cleaning.



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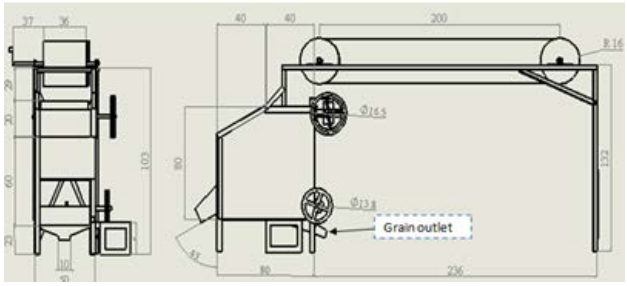

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Figure 1. Details of the Experimental Tef Chaff Separating and Grain Cleaning Machine (A = isometric view, B = section view; all dimensions are in cm)

The machine is easy to operate and convenient to service and maintain. The machine consists of a frame, a belt conveyor, an oscillating triple-screen assembly, a centrifugal blower and diesel engine as shown in fig. 1.

General specifications of machine are: overall length 316cm, overall width 50 cm, overall height 148 cm, power of 5hp, easy operation; minimum adjustments, reduced repairs and maintenance problems. Multi crop capability, includes three screens with interchangeable accordingly. Simple design includes integral shaft for horizontal oscillating screen drive and fan.

2.2. Parameters measured

Separation and cleaning process take place along the sieve length as grain and MOG (material other than grain) were transported over the sieve. During each test run materials leaving through MOG outlet and those leaving through grain outlet were weighted using digital balance in order to determine the separation efficiency, cleaning efficiency, separation loss and cleaning loss.

The performance evaluation of the separating and cleaning machine was made on the basis of the following parameters; separating efficiency, cleaning efficiency, grain loss and cleaning loss. As per Amer (2009) separation efficiency and grain losses were calculated using Eq. (1 and 2).

$$SE = \frac{M_1}{M_2} X 100\% \quad (1)$$

$$SL = \frac{M_4 - M_3}{M_4} X 100\% \quad (2)$$

Where: M_1 = the mass of impurities after separation and cleaning (kg), M_2 = the mass of impurities before separation and cleaning (kg), M_3 = the mass of grains after separation and cleaning (kg), M_4 = the mass of grains before separation and cleaning (kg), SE = separation efficiency (%) and SL = separation loss (%)

The cleaning efficiency and cleaning loss were calculated using the equations given by Werby (2010); Eq. (3 and 4).

$$CE = \frac{M_{css}}{M_{sbc}} x100\% - CL \quad (3)$$

Where: M_{css} = mass of clean grain sample (the mass of grains after separation and cleaning) (kg), M_{sbc} = mass of sample before cleaning (kg) and CL is cleaning loss (%);

$$CL = \frac{S_l}{S_o} x100\% \quad (4)$$

Where: CL = cleaning loss, S_l = grain lost behind machine ($M_4 - M_3$) in kg, S_o = grain output (M_3) in kg.

2.3.Experimental Design and Treatment

To evaluate the separating and cleaning performance of the prototype machine, three levels of sieve slopes (0, 5 and 10°), four levels of sieve oscillation (5, 10, 15 and 20 Hz) and four levels of feed rates (3, 6, 9 and 12 kg/min) were used. The experimental design was factorial in split-split plot, 3 x 4 x 4 having 48 experimental units. Each combination of an experiment (slope x oscillation x feed rate) was replicated three times the total numbers of test runs were 144. The sieve slope was taken as main plot while sieve oscillation and feed rate were take as sub-plot and as sub-sub plot, respectively. The air velocity at fan outlet throughout the experiment was kept constant at 3.2 m/s which were considered to be equivalent to the minimum terminal velocity of tef grains.

2.4.Statistical Analysis

Data were subjected to analysis of variance following a procedure appropriate to the design of the experiment as recommended by Gomez and Gomez (1984). Analysis was made using Gen Stat 15th edition statistical software. The treatment means that were different at 5% and 1% levels of significance were separated using LSDT.

3. Result and Discussion

The air velocity over the sieve unit was kept close to the terminal velocity of tef grain. Oscillations of the sieves were made by using a four-bar linkage mechanism where the legs of the sieve holding frame were pinned and oscillated about a vertical plane.

3.1.Effect of sieve slope on separation efficiency and separation loss

As can be seen from Figure 3 (a) increase in sieve slope from 0 to 5 degrees increased separation efficiency from 64.72 to 73.37%; further increase in sieve slope, to 10 degrees, resulted in decreasing separation efficiency to 61.39%. This was due to the very fact that the grains moved out of the separation unit with the MOG because the greater force ($mgsin\alpha$) acting on the entire material, grain and chaff, down the slope and the difference between gravity component and inertia component of forces ($mgcos\alpha < m\omega^2 r$) that lead to sliding rather than tossing and flailing the grain and chaff (Figure 2). This implies that at 10° sieve slope, the sieve tended to convey the grain and straw mixture before being sieved and sifting thoroughly. Consequently, grains went out with chaff through MOG outlet. The separation loss decreased from 12.95 to 10.20% as sieve slope increase from zero to 5 degree. Nonetheless, the separation loss increased to 18.08% as sieve slope increased from 5 to 10 degrees (Fig. 3(a).

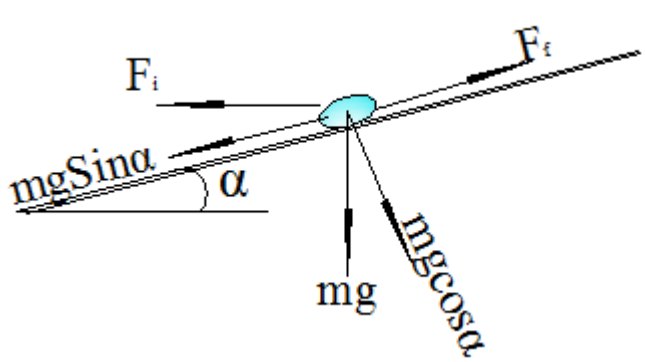


Figure 1. Forces acting on materials and their direction over the sieve surface (F_i=inertia force and F_f =friction force)

3.2.Effect of sieve oscillation on separation efficiency and separation loss

Separation efficiency tended to decrease with increasing sieve oscillation while separation loss increased with increasing sieve oscillation (Figure 3(b). The increase in the separation loss was from 4.93 to 22.64 % as sieve oscillation increased from 5 to 20 Hz. The decrease in separation efficiency and increase of separation loss with increasing sieve oscillations may be due to less resident time of materials to be separated on the sieve. Higher sieve oscillations, forced grains and chaff to bounce without adequate time to reside on the sieve so that the separation and cleaning to take place, hence poor or low level separation became eminent leading into low separation efficiency and high separation loss. Voicu *et al*, (2011), concluded that high oscillation frequency lead, in general, to faster movement of grains on the sieve, hence less time was available for the grains to pass through materials on the sieve and sieve holes. They also indicated that at high sieve oscillation, grains and chaff be 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.

3.3.Effect of feed rate on separation efficiency and separation loss

Figure 3(c) indicates that separation efficiency decreased with increasing feed rate while the separation loss increased with increasing feed rate. Increasing feeding rate from 6 to 12 kg/min decreased the separation efficiency from 72.69 to 55.98% while separation loss increased from 10.6 to 20.66% and effect was highly significant at ($P < 1\%$) (Table 1). The low separation efficiency and the high separation loss with the increasing feed rate could be due to the thick layer of material (matting of grains and chaff) formed on the sieves that constrained penetration of grain through the mat of materials on the sieves. Hence, effect of the feeding rate could be seen as increasing of the thickness of mixture of grain and chaff layer on sieve. Above all, at higher feed rate, it takes a long duration of time for the grain to be separated from the MOG due to the denseness of the MOG that made diffusion of the grain through the MOG sluggish.

3.4.Combined Effect Sieve Slope, Sieve Oscillation and Feed Rate on Separation Efficiency and Separation Loss

Analysis of variance made in Table 1 indicates that the effect of sieve slope, sieve oscillation and feed rate were highly significant ($P<0.01$) on both separation efficiency and separation loss.

Table 1. Analysis of variance of the result of the performance of the machine

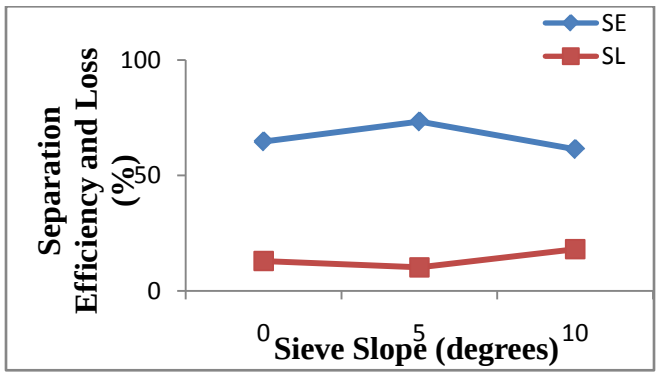
		F-value			
Source of variation	**D.F**	Separation Efficiency	Separation Loss	Cleaning Efficiency	Cleaning Loss
Replication	2				
SS	2	1684.4**	220.76**	179.4**	156.14**
SO	3	26058.02**	450.03**	433.42**	407.98**
FR	3	1960.44**	260.47**	217.73**	189.98**
SS x SO	6	2076.2**	19.49**	20.86**	21.27**

SS x FR	6	41.69**	2.55*	3.25*	3.73*
SO x FR	9	33.43**	7.52**	9.36**	10.5**
SS x SO x FR	18	39.14**	3.7**	3.19**	2.92**
Error	72				

*, **; significant at 5% and 1% probability level, respectively; D.F degree of freedom

Sieve slope and sieve oscillation (SS x SO), sieve slope and feed rate (SS x FR) and sieve oscillation and feed rate (SO x FR) combinations had highly significant (P<0.01) effect on both separation efficiency and separation loss except that SS x FR combination had significant effect at P<0.05 on separation loss. Separation efficiency and separation loss were dominantly affected by sieve slope and sieve oscillation and followed by sieve slope and feed rate and sieve oscillation and feed rate. The high separation efficiency and low separation loss were obtained at 3 kg/min feed rate, 5° sieve slope and 5 Hz of sieve oscillation.

The combined effect of sieve slope, sieve oscillation and feed rate (SS x SO x FR) was also highly significant (p<0.01) on separation efficiency and separation loss. In generally, separation efficiency decreased with increasing sieve oscillation and feed rate while separation loss was increased with increasing feed rate and sieve oscillation.



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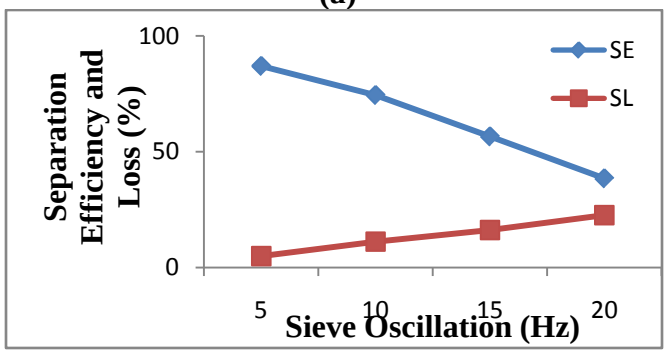

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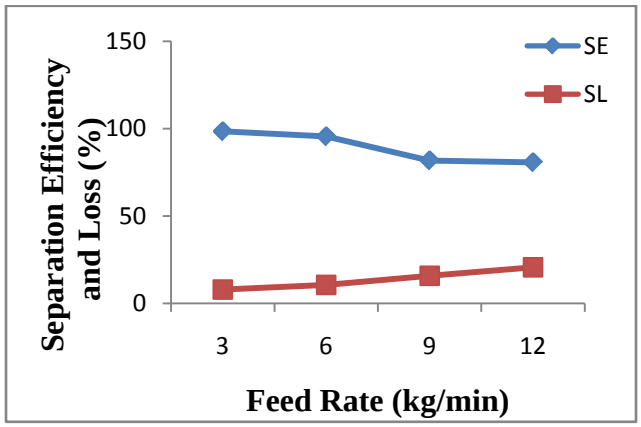
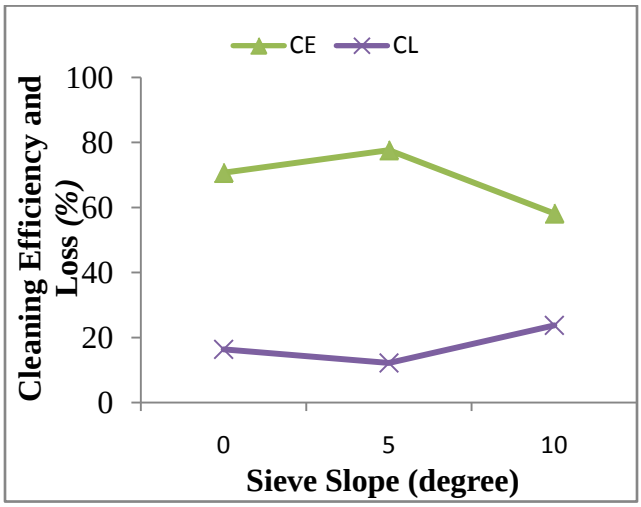


(c)

Figure 3. Effect of sieve slope, sieve oscillation and feed rate on separation efficiency and separation loss.

3.5.Effect of Sieve slope on Cleaning Efficiency and Cleaning Loss

As shown in Figure 4(a) increasing the sieve slope from 0 to 5 degrees lead to slightly increase cleaning efficiency and decreased cleaning loss. Increasing this slope to 10 degrees resulted in declining cleaning efficiency and increasing of cleaning loss. The phenomenon was common to all levels of sieve oscillations and feed rates and at sieve slope of 10 degrees grains were lost with chaff through MOG outlet.



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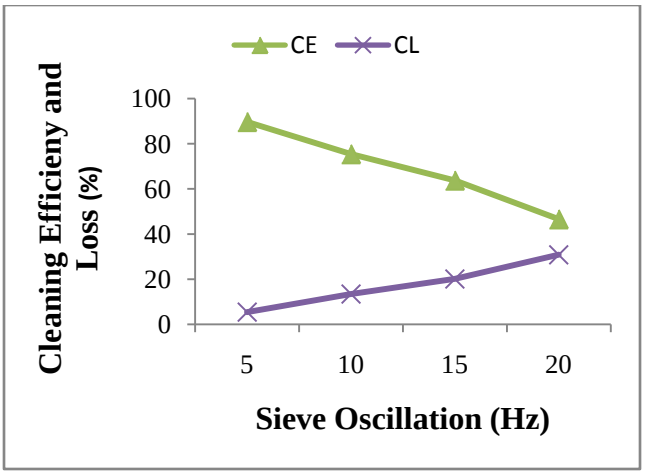

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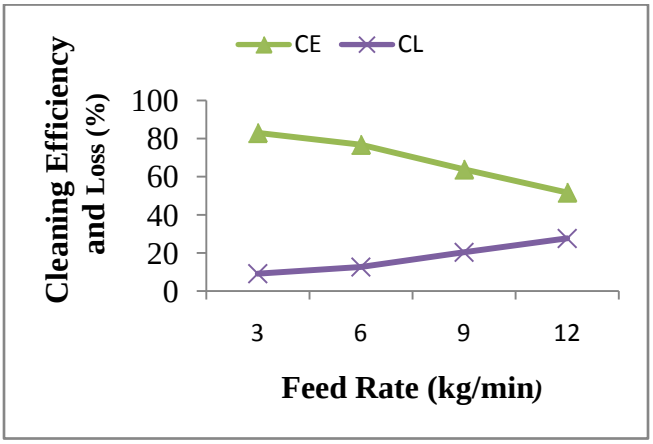

(c)

Figure 4.The Effect of Sieve slope, Sieve oscillation and Feed rate on Cleaning Efficiency and Cleaning Loss.

3.6.Effect of Sieve oscillation on cleaning efficiency and cleaning loss

Increase in sieve oscillation, in general, lead to decreased cleaning efficiency and increased cleaning loss at different sieve slopes as shown in Figure 4(b). The mean values of the cleaning efficiency was decreased from 89.65 to 46.55% and cleaning loss was increased from 5.41 to 30.81% as sieve oscillation increase from 5 to 20 Hz, respectively. This was due to the fact that at higher sieve oscillations some grains and chaff could be forced to leave the cleaning unit with the chaff because of high inertia force acting on them, hence going through the sieve perforations would not be possible and the situation becomes worst when sieve slope increased.

3.7.Effect of feed rate on cleaning efficiency and cleaning loss

Figure 4(c) shows the relationship between cleaning efficiency, cleaning loss and feed rate. The declining cleaning efficiency and increasing cleaning loss with increasing rate of feeding was

due to the formation of a thick layer of material on sieves that considerably hindered or limited passage of grains through the sieve perforations. The increasing in cleaning loss and decreasing of cleaning efficiency with increasing feed rate could be attributed the load intensity on the sieve that could result in matting of the sieve with material other than grain blocking sieve holes. Furthermore, whenever there are high feed rate, the current supplied will not be capable of suspending and blowing the materials aerodynamically as multiple particles act as obstruction to airflow. For aerodynamic separation to occur, the particles in a mixture must be accelerated as free dispersed bodies and not as a mat, hence feed rate must be limited to 6 kg/min if the prototype machine has to be used.

3.8. Combined Effect of Sieve slope, Sieve oscillation and Feed rate on Cleaning Efficiency and Cleaning Loss

The calculated values and figures plotted clearly indicated that the cleaning efficiency decreased with increasing sieve oscillation and feed rate while the cleaning loss was increasing with increasing sieve oscillation and feed rate (Figures 4). Analysis of variance presented in Table 1 indicates that the effect of sieve slope, sieve oscillation and feed rate were highly significant ($P<0.01$) on both cleaning efficiency and cleaning loss. The combined effect of sieve slope and sieve oscillation (SS x SO), oscillation and feed rate (SO x FR) were highly significant ($P < 0.01$) on both cleaning efficiency and cleaning loss. The combined effect of sieve slope and feed rate (SS x FR) was significant ($P < 0.05$) on cleaning efficiency and cleaning loss. The second-order interactions between sieve slope, sieve oscillation and feed rate (SS x SO x FR) was highly significant ($P < 0.01$) on both cleaning efficiency and cleaning loss. Table 10 presents the effect of the interaction between sieve slopes, sieve oscillation and feed rate at LSD 5%.

3.9.The Multiple Regression Analysis

The multiple regression analysis made the level correlation coefficients were used to identify parameters that had a dominant effect on separation and cleaning efficiencies and associated losses. From the equation given in Table 2 one can note that the dominant effect of feed rate except on separation efficiency.

Table 2. Multiple regression equation of parameters studied.

Regression	Equation	R^2
SE Vs SS, SO and FR	SE = 128.044 -0.52xSS -3.21xSO -2.593xFR	0.834
SL Vs SS, SO and FR	SL = -14.231 +0.513xSS +1.163xSO +1.45xFR	0.824
CE Vs SS, SO and FR	CE = 137.008 -1.251xSS -2.82xSO -3.558xFR	0.802
CL Vs SS, SO and FR	CL = -22.78 +0.738xSS +1.657xSO +2.108xFR	0.783

3.10. Conclusion

Performance evaluation to quantify the effects of the sieve slopes, sieve oscillations and feed rates on separation and cleaning efficiencies and associated losses when separating chaff and cleaning tef grains and chaff was made. Three levels of sieve slopes, four levels of sieve oscillations and four levels of feed rates were investigated to identify the optimum combination of the variables in question. Based on the performance evaluation made and results obtained, the following conclusions can be drawn:

- The performance of the machine was significantly affected by feed rate, sieve oscillation and sieve slope in that order of dominancy;

- Separation and cleaning efficiencies in general decreased with the increasing sieve oscillation and feed rate, while separation and cleaning losses increased with the increasing sieve oscillation and feed rate;

- The separation efficiency slightly increase as sieve slope increase from 0 to 5 degrees but further increase of sieve slopes up to 10 degrees kept on reducing the efficiencies of separation and cleaning;

- The separation and cleaning losses were decreased as sieve slope increased from 0 to 5 degrees and increased as sieve slope increased to 10 degrees;

- High levels of feed rate and sieve oscillation is considered are inefficient and cannot obtain satisfactory or acceptable efficiencies and losses;

- The study clearly indicated the optimum combination of sieve slope, sieve oscillation and feed rate to be 5 degree, 5 Hz and 3 kg/min, respectively for the prototype machine developed; and

- The multiple regression analyses made and the equations developed can be used as corner stones and spring boards to select optimum combination of the variable parameters to further develop and/or improve seeds and grains separating and cleaning machine.

3.11. Recommendation

Based on the findings obtained, the following recommendations are made:

- Since the belt conveyor was operated manually, the uniformity of feed materials into the cleaning unit was not consistent; hence an automatic feeding must be developed and used;
- Oscillations on the sieves were developed using a four-bar linkage mechanism that make the displacement of the stacked sieves different, the efficiencies and losses might have be affected by the variation in the displacements of sieves; hence, slider crank mechanism be considered as an appropriate option for equal displacement of stacked sieves;

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