Effect of designed threshing unit on performance of Teff [*Eragrostistef* (Zucc.) Trotter] thresher

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Abstract: Teff (Eragrostistef (Zucc.) Trotter) is atypical crop growing in most areas of Ethiopia, with the first area coverage. Threshing of *teff* can be performed indifferent ways; by hand beating, animal trampling and use of stationary threshers. In all cases of teff threshing, separation and cleaning are the most tedious and time consuming activities. In this research, the design effect of a newly developed type threshing unit was compared against SG-2000 stationary thresher. The comparison was focused on two independent variables: feed rate and drum speed, with three levels 275, 325 and 400 kg hr^{-1}; and 22.04, 24.49 and 29.39 m s^{-1}, respectively. The results revealed that mean values of the threshing capacity, cleaning efficiency and separation efficiency are 42.30 and 45.81 kg hr^{-1}; 24.85% and 35.92%; and 86.33% and 93.10% for SG-2000 and the newly developed threshing units, respectively. The newly developed threshing unit (closed type concave) showed significant difference in separation and cleaning efficiency of teff over SG-2000 (the open concave type). To perform closer to 100% cleaning efficiency, it is recommended to adopt other mechanism or use of additional sieves under the concave.

Keywords: cleaning, concave, drum, separation, teff threshing units, threshing

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1 Introduction

Threshing is a key part of agriculture that involves removing the seeds or grains from the chaff or plants from the plant stalk). This may be accomplished by impact between the heads and a fast moving element, rubbing, squeezing or a combination of these methods (Miu, 2016). Threshing is breaking grain free from other plant material by applying mechanical force that creates a combination of impact, shear, and/or compression. It is important to avoid damaging grain during threshing, a challenging task under certain crop conditions. Threshing can be performed with different methods. In the case of small farms, threshing is done by beating or crushing the grain by hand or foot, or stick, which requires a large amount of hard physical labor. Animal trampling is also a method of threshing in most developing countries. A simple thresher with a crank can be used to make this work much easier for a farmer. The conventional tangential threshing unit threshes mostly by impact. Other threshing devices like

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rotary threshing units act more by rubbing where the crop is axially or tangentially fed into the rotors which are more popular (Miu, 2016).

After threshing operation, the next steps are separation and cleaning of seeds from other material. The operation of separation refers to separating threshed grains from the bulk of plant material such as straw. The cleaning operation uses air to separate fine crop material such as chaff from grain (Christopher, 2011). The three operations can be performed separately /like in animal trampling or stationary threshers using forks and winnowing equipment/ or in one machine like combine harvester.

In Ethiopia, teff is the most important crops and used as staple food for most Ethiopians. Threshing of teff is carried out by trampling over the cut crop (Figure 1), collected on a flat surface with oxen. However, this method is very time consuming and laborious activity not only for threshing, but is also difficult for separating the seed from the chaff and cleaning the grain. Separation of teff grain is carried out by winnowing (throwing the grain and material out of grain mix in air) using the difference in aerodynamic properties of each mixture. Cleaning is performed by manually wafting air over the grain chaff mix with a dried hard leather strap (Bultosa and Taylor, 2004). To address such problems, different governmental and nongovernmental as well as private institutions came up with different solutions like promoting appropriate stationary threshers (Figure 2). Most threshers are non-cleaning and they are not well accepted either for threshing teff or for other cereals. The SG-2000 model is similar with the original Nigerian model, IITA cereal thresher, modified by different governmental, nongovernmental institutions and private companies. The main problem remains the same, even though different modification was performed, especially for cleaning of teff from material other than grain.

Threshing efficiency is the percentage of the threshed grains calculated on the basis of the total grains entering the threshing mechanism.

It increases asymptotically with concave length up to a certain point. Following the design procedures (Pahl *et al*., 2007), a new teff threshing units was developed

So, this study shows the effect of the threshing units (concave and drum) on the performance of teff threshing mechanisms.

2 Methodology

2.1 Design requirements

There are different methods of teff threshing, like animal trampling and non-cleaning stationary thresher, but most of them are not appropriate for efficient cleaning and better output capacity for teff threshing. Hence, end users are required for threshing mechanism with better cleaning and separation efficiency as compared with the existing threshing system. And to start designing, the overall size or dimensions of the threshing units were considered from the existing threshers (stationary threshers available in the country SG-2000 (Figure 3).

So, to develop a new threshing mechanism, the major requirements were listed as follows:

(1) Increase the cleaning and separation efficiency by 20%-30% from SG-2000 thresher

(2) Increase the capacity by 10%-15% from SG-2000 model thresher

(3) Easy for manufacturing and maintenance

(4) The thresher units should be manufactured from easily available raw materials

(5) The size of threshing unit should be equal with the SG-2000 model thresher

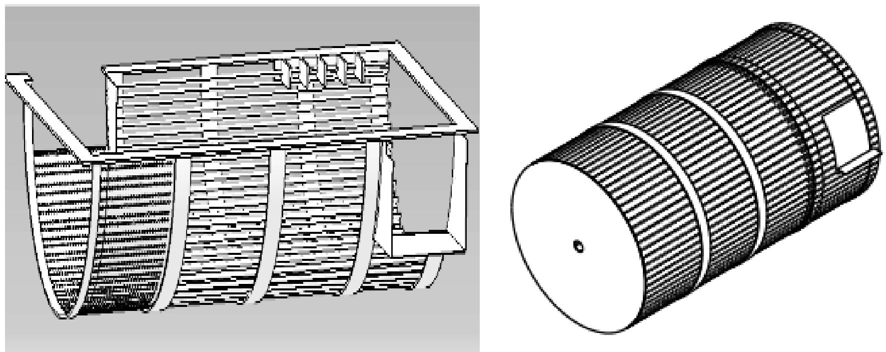
2.2 Design of concave

The concave performs two functions. It must support the threshed material in order to maintain the rubbing or impact action, and allow the maximum possible amount of threshed material or mixture with grains. The amount of grain damage increased with concave length since the grain which was not separated through the concave was subjected to a greater number of impacts before leaving the threshing crescent. For the case of very small grains like teff, the equivalent diameter was reported to it vary between 0.71 and 0.87 mm and thousand grain mass 0.257-0.421g (Zewdu, 2007). There is no much doubt for damage with the increment of concave length rather, the concave length increment may affect and increase the separation rate of *teff* threshing. There were comparative studies conducted on concave openness with the two concaves types, open and closed type by Arnold and Lake (1964) on wheat crop. The results were four times many damaged kernels in the samples produced, using closed concaves. For small grains where the grain damage is not a serious problem, there is a possibility to use both types. The concave area is very important for separation where the increment in the area will directly be proportional to the separation rate. This was clearly indicated by Eric and Wall (1986) studies where the weight of foreign material passing through the concaves generally increased as the percent area of the concave increased.

So based on all test results and assumptions, the closed type concave is the best option for *teff* threshing unit (Figure 3b). The size (diameter and length) of the concave was the same as the SG-2000 thresher (Figure 3a). In order to have better separation in the threshing units, the concave opening should be just like the shape of the *teff* seed that is almost round and the diameter of the opening is determined accordingly (Miu, 2016).

Figure 1 Animal trampling (for *teff* threshing and cleaning) in Adet, Ethiopia

Figure 2 SG-2000 multi crop thresher and its threshing units

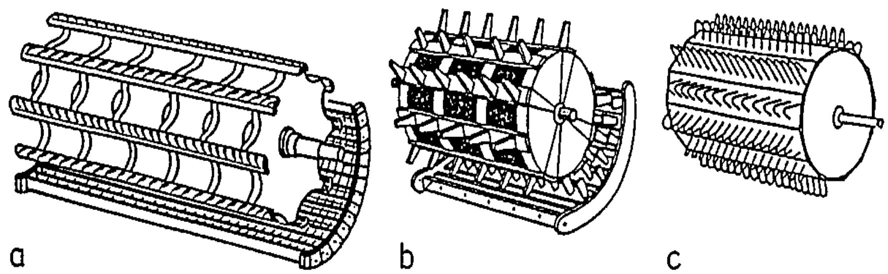


a) SG-2000 concave (open) b) Round (closed) concave

Figure 3 Open (SG-2000) and closed concaves

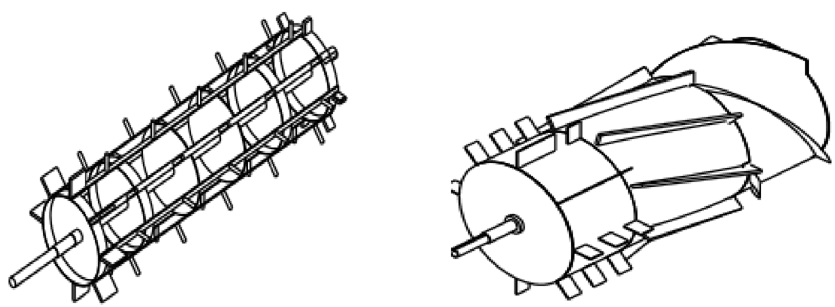
2.3 Design of drum

There are different types of drum, the type of drum can be classified based on the power required on the threshing compartment and the type of crops to be threshed (Figure 4). The efficiency of the thresher is mostly determined by the type and shape of the thresher drum. Separating efficiency of an axial flow threshing cylinder largely depends on the length and diameter of cylinder (or area of separation) and the peripheral speed of the cylinder (Chimchana et al., 2008). The power consumed by the thresher should be transferred through the drum shaft. So the size of the drum shaft was calculated based on the power required for *teff* threshing and the required power was calculated according to Baru and Pansesar (2005). Nowadays, the axial type thresher drum is versatile and widely used.



(a) rasp bar (b)spike tooth (c) wire loop;

Figure 4 Threshing cylinders types



(a) SG-2000 thresher drum (b) Newly developed *teff* thresher drum

Figure 5 SG-2000 thresher and newely developed teff thresher drums

The stationary threshers are focusing on the advantage of the axial type drum; SG-2000 drum (Figure 5a) and the newly developed *teff* thresher drum (Figure 5b) are designs based on the axial type drum. Construction of this drum consists of three parts, the first is a feeding zone as auger with four helical shape blades with 90^o apart each other, the second is the threshing zone with eight rectangular bar welded at 30^o from the center and the third part is straight flat sheet welded perpendicular to the drum for chopping and throwing out the straw (Figure 5b). To have higher cleaning efficiency the area of the concave and the size of the threshing drum has effect (Miu, 2016).

2.4 Test conditions and experimental set up

The threshing unit has 0.96 m concave width and the drum diameter is 0.48 m. The newly developed threshing unit consists of the round concave and drum with three parts (Figure 5b). The test material *teff* (Dz-Cr-387/RIL-355)/Quncho/ was planted and harvested at Adet Agricultural Research Centre (North-west Ethiopia). *Adet* is located at altitude and longitude of 11°16'N 37°29'E Coordinates: 11°16'N37°29'E with an altitude of 2.216 meters above sea level. The test was performed at a research Center. The 10 kg bulk of *teff* were prepared for each test and it feeds manually. Feeding trough made of mild steel sheet thickness of 1mm with 1200 × 700 mm base area and 1000 × 300 mm opening size was used for feeding the crop in threshing unit. In this design a height of feeding table was determined considering an average of farmers' height which could be appropriate for easy and comfortable feeding of the crop. The tray was hinged with the frame and can be folded during transport.

The test material parameters were measured as in the (Table 1). For the experiments the threshing test stand was developed with equal boxes which are mounted below the threshing and separating system. The experimental setup was designed based on the set up of Simonyan and Yilijep (2008) research.

The concave area was partitioned perpendicular to the rotor axis in seven equal sections, with the size of 100 mm width. The separated masses of the new threshing units are caught in the boxes 1 to 7 (*teff* with mixture of straw and chaff) sack as box 8 for straw collection (Figure 6). For the SG-2000 model threshing unit the separated mass are caught in the boxes 1 to 6 (*teff* with mixture of straw and chaff) the 7th box was under the straw outlet /as its original construction is covered with sheet metal/ and sack as box 8 for straw collection. The gathered materials in the boxes are weighed and cleaned to quantify the part of grain and the part of material other than grain /MOG/ in each box. The dimension of each box has 100mm width and its height is attached with the concave bottom. The overflow is caught in the other sacks. Separation and cleaning are performed manually (Figure 7).

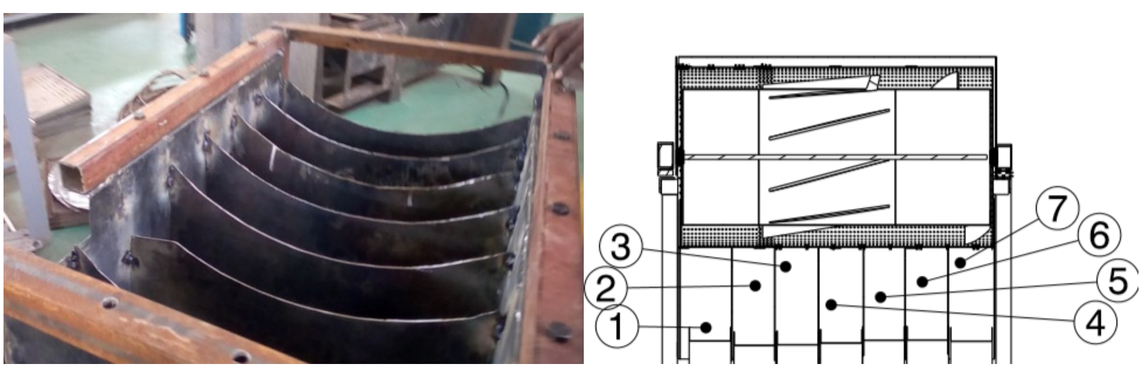


Figure 6 Sample (*tef*, straw and chaff mixture) collectors box 1-7

Grain samples from the threshing and separating section are drawn for measuring the part of clean grain (*teff*), chaff and straw with sensitive (digital) balance. The test /operation/was done manually (controlled feed) where the speed of the drum was measured with digital tachometer with time of operation recorded using stopwatch and other observation around the threshing units. There were two independent variables (feed rate and rotational speed of the drum) i.e. feed rate in three levels (400, 325 and 275 kg hr^{-1}) and rpm 29.39, 24.49 and 22.04 m s^{-1} and three dependent variables (threshing capacity, cleaning efficiency and separation efficiency) used for comparison of two threshing units. The test crop parameters are listed in Table 1.

Figure 7 Manual cleaning and separation of samples (straw, chaff and teff mixture) from each sample box

Separation efficiency at the current position of the separation length is defined as the ratio between the separated grain mass on the differential interval *dx* and the available grain mass to be separated to the rear of the threshing unit. This can be mathematically expressed as indicated in Miu (2016):

$$eff_s = \frac{S_d}{1-(V_t+S_s)} \times 100 \qquad (1)$$

Where: eff_s is the separation efficiency (%), S_d is the grain separation frequency along the length of the separation space, S_s is the separated grain along the length of the separation space or separation loss (%),and V_t is un-threshed grain becomes threshing loss (%).

Cleaning efficiency can be determined by the ratio of whole grain and the whole threshed material. Mathematically it is possible to write in the formula:

$$eff_{cl} = \frac{K}{L} x100 \qquad (2)$$

Where: eff_{cl} cleaning efficiency (%), *K* is mass of whole grain at main grain outlet per unit time (g), and *L* is mass of the whole material at main outlet per unit time (g).

The output capacity was measured by weighing the grains collected from the sample collector boxes with the time spent in the threshing operation. Sensitive balance with 0.005g calibration was used for weighing clean grain and chaffs. Teff bulk was measured using lift balance with 0.1 g scale. Time was measured using a stopwatch. Moisture content of crop was determined by oven dry method at a temperature of 103°C for 24 h (Smith et al., 1994). The bulk density was found by mass– volume method under natural filling condition.

Figure 8 Comparison of threshing units newly developed & SG-2000 threshing unit (manual feeding)

Digital tachometer (model C- compact Advent Optical Tachometer) was used for drum speed measurement. A meter ruler and vernier caliper were used for length measurements.

2.5 Statistical analysis

A 2×3×3 factorial was employed in Completed Randomized Design /CRD/ statistical design with three replications to evaluate the effect of two threshing units, SG-2000 and newly developed unit, three level of feed rate (F_1, F_2 and F_3; 400, 325 and 275 kg hr^{-1}

respectively) and three drum speed (R_1, R_2 and R_3; 1200, 100, 900 rpm respectively).

Experimental data were analyzed using analysis of variance (ANOVA) linear modeling, correlated with multi linear modeling, with Spearman methods. The means were compared with different range tests and graph construction in **Ri386.3.0.1** software.

Table 1 Crop varieties and test parameters

	Sample			
	1	2	3	Average
Variety / Parameters	Tef (Dz-Cr-387/RIL-355)quncho	Tef (Dz-Cr-387/RIL-355)/quncho	Tef (Dz-Cr-387/RIL-355)/quncho	Tef (Dz-Cr-387/RIL-355)/quncho/
Moisture content /w.b/ %	11.16	9.78	13.60	11.51
Grain/straw ratio	1:8.1	1:6.4	1:4.2	1:6.25
Length of the stem average, mm	430	590	520	513.33
Length of the panicle average, mm	250	320	510	360
Bulk density of the *Tef*, kg m^{-3}	32.81	37.80	34.06	34.96

Table 2 Summary of the results of threshers in response variables

	Capacity Kg.h^{-1}			Cleaning efficiency %			Separation efficiency %		
	Mean	Sd	cv%	Mean	Sd	cv%	Mean	sd	cv%
New thresher	45.81	11.32	24.71	35.92	8.36	23.75	93.10	2.06	2.21
SG-thresher	42.30	4.62	10.92	24.85	3.39	13.64	86.33	4.38	5.07

Table 3 ANOVAs table for *tef* threshing units

Variables parameters	Capacity Kg h^{-1}				Cleaning efficiency %				Separation efficiency %			
	Sum sq.	df	F value	Pr>F	Sum sq.	Df	F value	Pr>F	Sum sq.	df	F value	Pr>F
Thresher	166.5	1	2.218	0.143	1654.2	1	40	4.86e^{-08***}	9372.6	1	147.61	2.2e^{-16***}
Residuals	3915.2	52			2115.3	52			3301.7	52		

Note: Signif. codes '***' means p<0.001.

3 Results and discussion

Tables 2 and 3 show the newly developed *teff* threshing units have superior values for all dependent variables. The increment of its mean value in cleaning efficiency is higher than 10% and in separation efficiency is higher than 15%.

3.1 The relation of feed rate, rpm and concave length on the cleaning efficiency

The feed rate was controlled by the operator's skill. It was performed after a long trail and accustoming to feed in constant feed as much as possible. The shape of the drum was highly influence in charging and discharging without additional effort of the operator. The auger type of drum assists to pull the bulk of the crop immediately on the touch of the concave leap, in addition to this, the inlet chute of the thresher was at the lower side of the drum. As indicated in Figure 8 the newly developed drum has better cleaning efficiency than the SG-2000 thresher drum in all feed rates. The threshed material could distribute in a better way to the surface of the concave due to the shape of the beater and round concave.

The comparisons of result among threshing units showed that they have significant difference of cleaning efficiency under 99% of confidence (Table 3) This has happened because of the construction of the concave (round or closed) type (Figure 4b). It has more threshing area of contact than the open concave type and the drum, pushing the bulk immediately to the next part of the threshing compartment. This type of profile of the drum could have a possibility to push the bulk in the middle part of the drum instead of detaching the seeds at the inlet part. The operation is facilitating to have a minimum layer of the crop and mixture on the grain mat (the next sieve). In this case, it is possible to have additional cleaning mechanisms (shaking sieves with minimum layer) to get clean *teff* seed.

When the feed rate increases, the cleaning efficiency of the newly developed thresher shows increments with a certain level as shown in Figure 9 while SG-2000 thresher decreases. This could happen because of the area of the concave where the total area of the open concave SG model is 0.77m^2 and the newly closed type concave is 1.40 m^2.

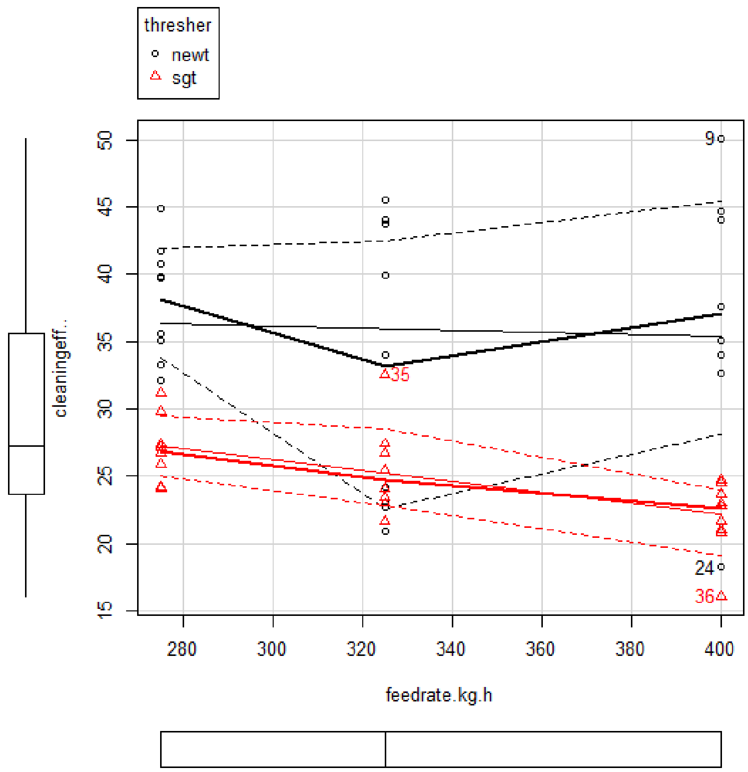


Figure 9 The effect of feed rate on cleaning efficiency of two threshing units

Table 4 ANOVA table for response variable cleaning efficiency

	df	Sum sq	Mean sq	F value
Federate	1	82.9	82.886	1.1542
Rpm	1	24.2	24.225	0.3373
Residuals	51	3662.5	71.813	

3.2 The effect of feed rate on the capacity of the threshing units

The capacity of threshing units is directly proportional to the feed rate: when the feed rate increases, the capacity of both threshing units increases with minimum capacity difference (Figure 10). The threshing capacity is highly influenced by the length and width of drum. Since the threshing units have equal size, the result shows that there is no significant difference between the two threshing units as indicated in the ANOVAs Table 5. The feed rate is highly significant standing at 99% of confidence interval.

Table 5 ANOVA table for response variable capacity

	df	Sum sq	Mean sq	F value
Federate	1	716.1	716.14	10.89**
Rpm	1	11.6	11.63	0.1769
Residuals	51	3354	65.76	

Note: Signif. codes '**' means p<0.01.

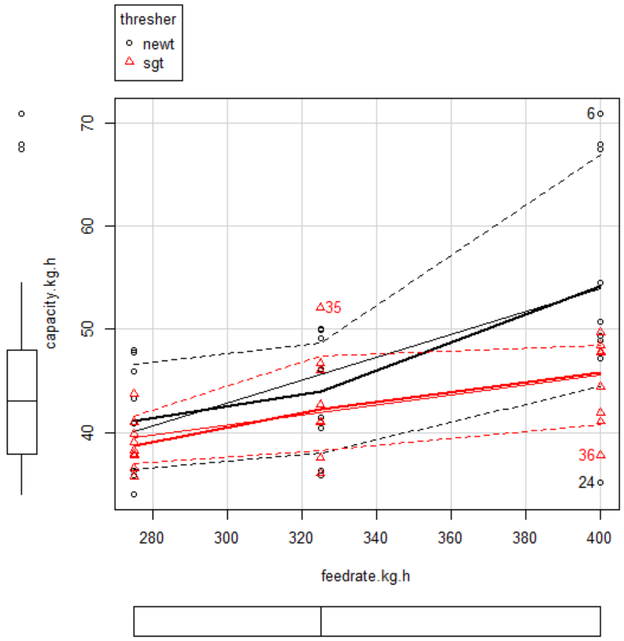


Figure 10 The effect of feed rate on capacity of two threshing units

3.3 The effect of feed rate on the separation efficiency

The feed rate has negative correlation with the separation of the threshing units between the two type of threshing units. As indicated in Table 6 and Figure 11, the optimum value of the feed rate can be predicted around 280 and 300 kg hr^{-1}.When the feed rate increases from 275 to 325 $kg.hr^{-1}$and, the separation efficiency decreases from 95.98% to 94.66%, from 86.57% to 81.02%; and when the feed rate increases from 325 to 400 kg hr^{-1} the separation efficiency decreases from 94.66% to 91.78% but increases from 81.07% to 85.98% for the newly developed and SG-2000 threshing units respectively.

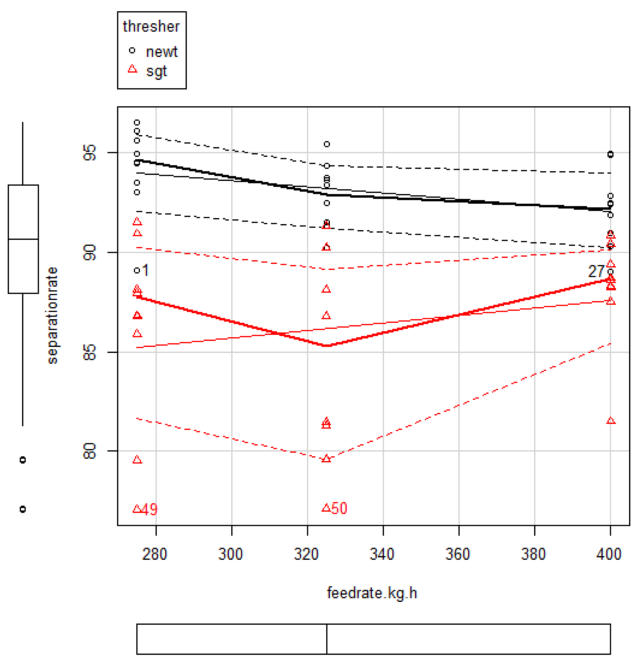


Figure 11 The effect of feed rate on separation efficiency of two threshing units

Table 6 ANOVA table for response variable separation efficiency

	Df	Sum sq	Mean sq	F value
Federate	1	451.9	451.86	1.8894
Rpm	1	25.2	25.19	0.1053
Residuals	51	12197.2	239.16	

3.4 The effect of drum speed (rpm) on capacity

The drum speed is correlated with the output capacity of both threshing unit—the SG-2000 has negative effect; however, the newly developed threshing units have a minimum positive effect (Table 6). In this test, at the initial speed of 900 rpm, the output was good. When the speed becomes 1000 and 1200 rpm, the capacity declines because of the properties of the stem of *teff* which has high tensile and could be rolled with the bars of the thresher drum in SG-2000 thresher. In the newly developed thresher after 1000 rpm again the capacity shows increments. This could happen in the closed type drum where the concave got opportunity to rub and cut the *teff* stem in a better way (Figure 12). In some researches the capacity has positive correlation with the drum speed (Dauda, 2001; Oni and Ali, 1986,; Anwar et al. ,1991; O'Ndirika, 2006; Enaburekhan,1994).

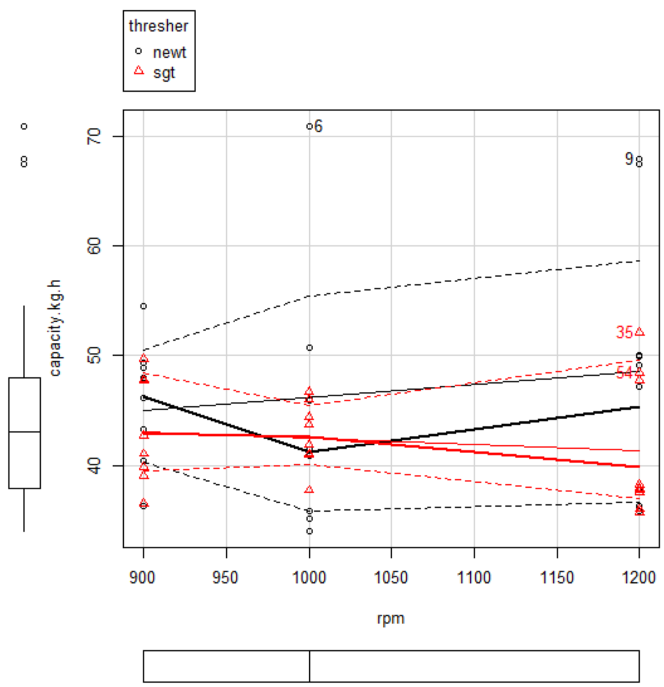


Figure 12 The effect of drum speed (rpm) on capacity of two threshing units

3.5 The effect of drum speed (rpm) on cleaning efficiency

The effect of drum speed on the–performance of cleaning has negative correlation for SG-2000 thresher and positive correlation for new developed thresher (Figure 13 and Table 7). When the drum speed increase from 900 to 1000 rpm, the cleaning efficiency decrease from 35.79% to 33.48% . However, when the drum speed increase from 1000 to 1200 rpm, the cleaning efficiency increases from 33.48% to 43.41% for the newly threshing units. This could happen because of the drum (auger) shape, easily pushing of bulk to the outlet. In the case of SG 2000 threshing unit, when the drum speed increases from 900 to 1000 rpm and from1000 to 1200 rpm, the cleaning efficiency decreases from 25.82% to 24.50% and 24.50% to 24.15% respectively. This could happen due to more impact /rubbing, resulting in more breakage of the bulk in the threshing units and more mixtures passsing under the concave.

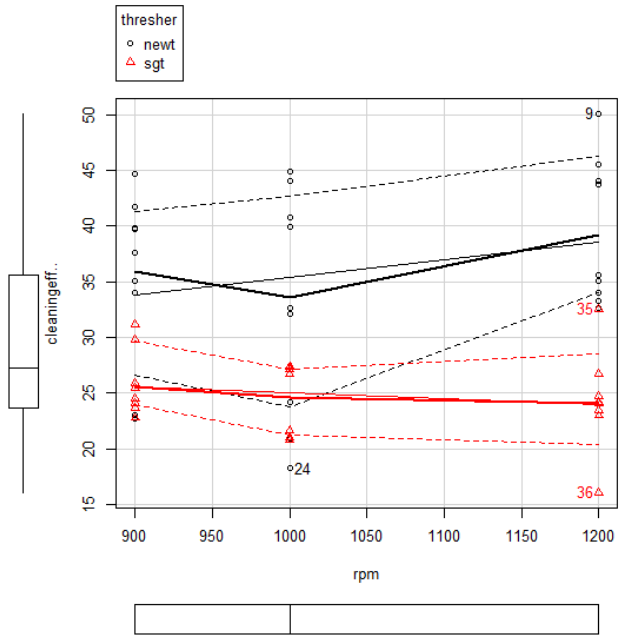


Figure 13 The effect of drum speed (rpm) on cleaning efficiency of two threshing units

3.6 The effect of drum speed (rpm) on the separation rate

The effect of drum speed on the performance of separation rate has negative correlation for SG-2000 thresher (Table 8) and positive correlation for newly developed thresher (Figure 14 and Table 7) As the general trend of the graph shows, when the drum speed increases from 900 to 1000 rpm, the separation efficiency increases from 91.66% to 96.66%. W hen the drum speed increases from 1000 to 1200 rpm, the separation efficiency decreases from 96.66% to 93.85% for the new threshing unit. Also,when the drum speed increases from 900 to 1000 rpm and from 1000 to 1200 rpm, the separation efficiency of SG 2000 threshing unit decreasings from 89.77% to 80.43% but increasing from 80.43% to 86.74% respectively. This could happen due to the configuration of the drum and concave. When the chopped material within the specified area is more, then the separation becomes difficult .As a general principle, the separation should be closed to 100%, but there was the overflow of the bulk material and beyond the separation rate. This could be accounted as overflow (loss).

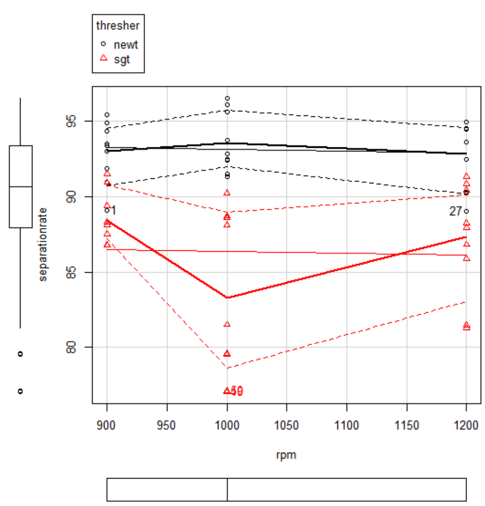


Figure 14 The effect of drum speed (rpm) on separation efficiency of two threshing units

Table 7 ANOVA table for response variable separation efficiency

	df	Sum sq	Mean sq	F value
Federate	1	451.9	451.86	1.8894
Rpm	1	25.2	25.19	0.1053
Residuals	51	12197.2	239.16	

4 Conclusion

The performance of teff threshing units at the existing size of the stationary threshers was evaluated in three response variables; capacity, cleaning efficiency and separation efficiency with two independent variables: feed rate with three level (400, 325 and 275 kg hr^{-1}) and drum speed with three level 29.39, 24.49 and 22.04 m s^{-1}.The results obtained, show that the mean values are 45.81 kg hr^{-1} and 42.30 kg hr^{-1}; 35.92% and 24.85% and 93.10 % and 86.33% and the maximum value obtained are 70.88 and 52.11 kg hr^{-1}; 50.2% and 32.14% and 96.53% and 91.52% for the newly developed (closed concave) and SG-2000 (open concave) threshing units respectively. The design parameters have significant effect on cleaning efficiency and separation efficiency at 99% of confidence interval. Still there is a gap to get 100% clean teff seed, however, the study which tried to focus on maximizing the cleaning and separation efficiency at the existing size of threshing units on which obtained the promising results. So, it is recommended for further study to improve the performance of the newly developed threshing units by optimizing the opening of the concave holes and incorporate additional shaking sieves under the concave.

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