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THE EFFECT OF THRESHING UNITS' DESIGN ON PERFORMANCE OF TEF [*Eragrostistef* (Zucc.)Trotter] THRESHER

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Abstract: *Tef (Eragrostistef (Zucc.)Trotter)* is atypical crop growing in most areas of Ethiopia, with the first area coverage. Threshing of *tef* can performed indifferent way, by hand beating, animal trampling and stationary threshers. In all cases of *tef* threshing the separation and cleaning are the most tedious and time consuming activities. The research compare the design effect of two threshing units SG-2000 stationary thresher and new developed threshing units in three variables: threshing capacity, cleaning efficiency and separation efficiency on two independent variables, feed rate and drum speed with three level 275, 325 and 400kg/hr; and 900, 1000 and 1200 rpm respectively. The mean value of the threshing capacity, cleaning efficiency and separation efficiency are 42.30 and 45.81kg/hr; 24.85% and 35.92%; and 33.61% and 59.96% for SG-2000 and new developed threshing units respectively. The new developed (closed type concave) has significant difference on separation and cleaning efficiency over SG-2000(the open type concave). To perform closer to 100 % cleaning efficiency it is recommended to search other mechanism and/or to have additional sieves.
Keywords: Cleaning, Concave, Drum, Separation, *Tef* threshing units

1. INTRODUCTION

Threshing is a key part of agriculture that involves removing the seeds or grain from 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 (Campbell, 1976). Threshing is breaking grain free from other plant material by applying mechanical force that creates a combination of impact, shear, and/or compression (Bill and Bernard, 1999). 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, and stick these requires a large amount of hard physical labour. Animal trampling is also the method of threshing in most developing countries. A simple thresher with a crank can be used to make this work much easier for the farmer. The conventional tangential threshing unit threshes mostly by impact; other threshing devices like rotary threshing units act more by rubbing. Rotary threshing units in which the crop is fed axially or tangentially into the rotor are becoming more popular (Bill and Bernard, 1999).

In most threshing operations the next steps is separation and cleaning seeds from material other than grains. The operation of separation refers to separating threshed grains from bulk 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 perform in separately /like animal trampling or stationary threshers using forks and winnowing equipments/ or in one machine like combine harvester.

In Ethiopia most threshing is done by animal trampling (Figure1), *tef* threshing is also done by this traditional method and this method is very time consuming and laboures activity not only for threshing it is difficult to separate and cleaning. *Tef* threshing is carried out by trampling over the cut crop collected on a flat surface with oxen. Separation of *tef* grain is carried out by throwing the grain and material out of grain mix in air using the difference in aerodynamic properties. Cleaning is performed by manually wafting air over the grain chaff mix with a dried hard leather strap (Bultosa and Taylor, 2004). To combat such problems different governmental and non-governmental and private institutions endeavors different solutions like promoting different appropriate stationary threshers(Figure2) developed by Rural Technology Promotion Centers (Asela, Bako, Bahirdar, Kombolcha..), Agricultural Mechanization Research Centers (Melkassa, Oromia and Amhara) in Ethiopia. Most threshers are non-cleaning and are not well accepted for threshing *tef*. The SG-2000 model is similar from the origin Nigeria model IITA cereal thresher and modified with different governmental non-governmental and private company. The main problem is the same /even though different modification performed/ especially for cleaning of *tef* from material other than grain. The Class combine could thresh *tef* easily, but the cleaning problem was occurring. The cleaning and separation of *tef* from the chaff and straw using the conventional technique /mostly air / is impossibly due to its small size. According to Zewdu, (2007) investigation concluded about the air separation technique that complete theoretical separation of *tef* grain from straw using air is not possible, particularly end-node straws have terminal velocities comparable or even greater than that of *tef* grains. 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. Increasing concave length beyond this point does not increase threshing

efficiency and might even decrease it under certain conditions (Miu et al., 1997). Threshing performance parameters are affected by design factors, operating parameters and crop conditions. Following the design procedures (Pahl et al., 2007) a new *tef* threshing units were developed.
So, this study shows the effect of the threshing units (concave and drum) on the performance of *tef* threshing mechanisms.

2. METHODOLOGY

— Design Requirements

There are different methods of *tef* threshing, like animal trampling, non-cleaning stationary thresher, but most of them are not appropriate for efficient cleaning and better output capacity. Hence, end users required threshing mechanism with better cleaning and separation efficiency compared with the existing threshing system. To start designing the overall size or dimensions of the threshing units are considered from the existing threshers (stationary threshers available in the country SG-2000 (Figure2).
For developments a new threshing mechanisms the major requirements are listed as follows:

- Increase the cleaning and separation efficiency by 20-30% from SG-2000 thresher
- Increase the capacity by 10-15% from SG-2000 model thresher
- Easy for manufacturing and maintenances
- Should be manufactured from easily available row materials
- The size of threshing unit should be equal with the SG-2000 model thresher

Figure 1.Animal trampling (for *tef* threshing) in Ethiopia

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

— Design of concave

The concave perform two functions. It must support the threshed material in order to maintain the rubbing or impact action, and it must allow the maximum possible amount of threshed material or mixture with grains. Arnold, (1964) reported that increasing concave length increased concave separation, for unit increase in concave length the proportion of grain separated is equal to $1- e^{-k}$, where e is the natural logarithms and k is the rate of constant. With crops that are easily threshed a longer concave produced little increase in threshing efficiency, however crops which were difficult to thresh the increase was not that much.
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 *tef* it is not much suspicious for damage and the length of concave is not affecting, rather the length of concave may affect and increase the separation rate of *tef* threshing. Cooper, (1978) studied on the effect of concave length when threshing crops like wheat and barley. He reported that a 25% increase of arc from 84° to 105° increase grain separation by 17%, but a similar increase of arc from 105° to 135° gave a smaller increase in grain separation, however the importance of increasing concave separation efficiency was emphasized when a 5% difference of concave separation between 105° and 135° and 20t/h (total feed rate) nearly halved the level of straw walker loss.
There were comparison studies in regard of concave openness, the two concave types, open and closed type was studied by Arnold and Lake, (1964) on wheat crop and they come up with the result that there were four times as many damaged kernels in the samples produced using closed concaves. For small grains where the grain damage is not series problem, there is a possibility to use both types. The concaves area is very important for separation the increment in the area will directly proportional with the separation rate. This was clearly indicated by Aric, (1986) studies that the weight of foreign material passing through the concaves generally increased as the percent area

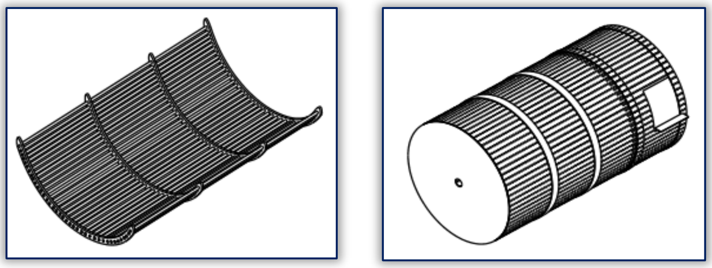

Figure 3.a) SG-2000 concave (open); b) Round (closed) new developed concave

of the concave increased. So based on all test results and assumptions the closed type concave is the best option for *tef* 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 as the shape of the *tef* seed that is almost round and the diameter of the opening was determined based on (Miu, 2016).

— 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 for the thresher should be transferred through the drum shaft. So the size of the drum shaft was calculated based on the power required for *tef* threshing and the required power was calculated based on (Baruah and Pansesar, 2005). Now a day the axial type thresher drum is versatile and widely used. The stationary threshers are focusing on the advantage of the axial type drum; SG-2000 drum (Figure 5a) and the new developed *tef* thresher drum (Figure5b) are design based on the axial type drum. Construction of this drum consists three parts, the first is a feeding zone as auger with four helical shape blades with 90° apart each other, the second is the threshing zone with eight rectangular bar welded at 30° 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 better cleaning efficiency the area of the concave and the size of the threshing drum has effect (Miu, 2016).

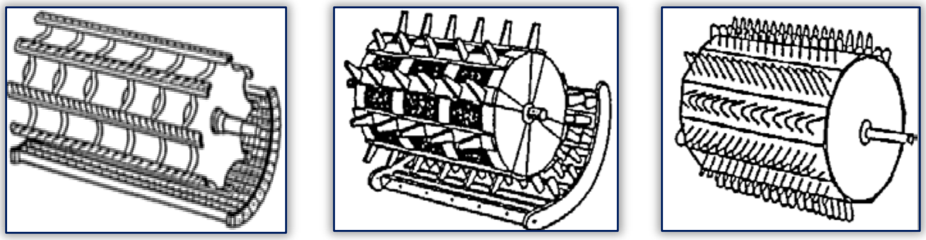

Figure 4. Threshing cylinders type; a) rasp bar; b) spike tooth; c) wire loop (Bill and Bernard, 1999).

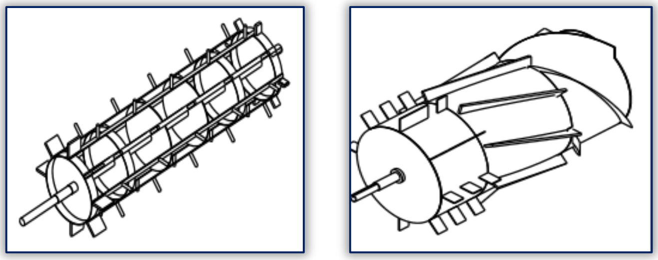

Figure 5. a) SG-2000 thresher drum; b) New developed tef thresher drum

— Analysis of drum shaft

The power is transmitted from the engine through the pulley to the shaft and rotating drum. The size of the shaft was determined based on the maximum moment and tension forces at the end of the shaft and is calculated manually and checked with the dynamic analysis using the software (Figure 6). The result of the analysis shows the shaft is well safe for the specified task. The maximum deflection (transitional displacement) is 0.45mm.

$$\delta = 0.001L - 0.003L in mm$$

where: δ is deflection or transitional displacement in mm, L is the distance (length) between to support (bearing center) in mm

In our case the δ limit is 0.96-2.88mm. Then the actual maximum deflection of the drum shaft 0.45 mm is less than 0.96mm.

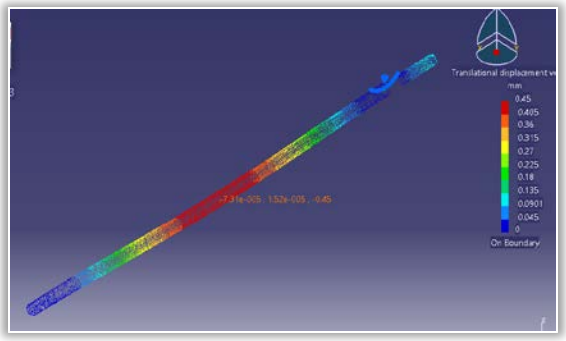

Figure 6. The drum shaft analysis

— Test conditions and experimental set up

The threshing unit has 0.96m concave width and the drum diameter is 0.48 m. The new developed threshing unit consists the round concave and drum with three parts (Figure 5b). The test material *tef* (Dz-Cr-387/RIL-355)/Quncho/ were planted and harvested in Adet Agricultural Research Center. The test performed at Adet Agricultural Research Center. The 10 kg bulk of *tef* were prepared for each test and it feeds manually. 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 concave area was partitioned perpendicular to the rotor axis in seven equal sections with the size of 130 mm width. The separated masses of the new threshing unit are caught in the boxes 1 to 7 (*tef* with mixture of straw and chaff) sack as box 8 for straw collection (Figure 7) and for the SG-2000 model threshing unit the separated mass are caught in the boxes 1 to 6 (*tef* with mixture of straw and chaff) the 7th box was under the straw out let /due to its original construction is covered with sheet metal/ and sack as box 8 for straw collection. The gathered materials in the boxes are weighted and cleaned to quantify the part of grain and the part of 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 8).

Figure 7. Sample (tef, straw and chaff mixture) collectors

Figure 8. Manual cleaning and separation of samples (straw, chaff and tef mixture) from each sample box

The output capacity was measured by weighing the grains collected from the boxes with the time given in the threshing operation. Weight measurement used with the sensitive balance with 0.005g calibration (Figure 10a.) was used for weighing clean grain and chaffs, for measuring the tef bulk used the lift balance with the 0.1g 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 weight – volume method under natural filling condition.

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

— Statistical Analysis

A 2X3X3 factor factorial was employed in CRD statistical design with three replications to evaluate the effect of two threshing units, SG-2000 and new developed, three level of feed rate (F_{R1}, F_{R2} and F_{R3}; 275,325 and 400 kg/hr respectively), at three drum speed (R_1,R_2 and R_3; 900,100,1200 rpm respectively).

Grain samples from the threshing and separating section are drawn for measuring the part of clean grain (*tef*), chaff and straw with sensitive (digital) balance (Figure 10a). The test /operation/was done manually feed (controlled feed), the speed of the drum were measured with digital tachometer (Figure 9), time of operation recorded with stopwatch and other observation around the threshing units were recorded. There are two independent variables (feed rate and rpm), feed rate in three level (400,325 and 275 kg/hr) and rpm in three level (1200, 1000 and 900 rpm) and three dependent variables (threshing capacity, cleaning efficiency and separation efficiency) used for comparison of two threshing units. Test crop parameters are indicated on the table1.

Figure 9. New developed threshing unit (manual feeding) under test

Figure 10. a) Sencitive balance for measuring samples weigh; b) Optical tachometer

Experimental data were analyzed using analysis of variance (ANOVA) linear modeling, correlated with multi linear modeling, with Spearman methods and the means were compared with different range tests and graph construction in R i386.3.0.1 software.

Table 1. The test crop parameters

Variety	Sample			
	1	2	3	average
	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

3. RESULT AND DISCUSSIONS

The data collected during machine operation was statistically analyzed and the test result and the summary of the Analysis of Variance (ANOVA) depicted in the Table 2 and 3 respectively. The new developed *tef* threshing units showed its superior value in all dependent variables. The increment of its mean value in cleaning efficiency is more than 10% and in separation efficiency is more than 15%.

Table 2. Summary of the result of threshers in response variables

	Capacity Kg/h			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	59.96	9.21	15.36
SG-thresher	42.30	4.62	10.92	24.85	3.39	13.64	33.61	6.48	19.27

Table 3. ANOVAs table for *tef* threshing units

Variables parameters	Capacity Kg/h				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		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

— The effect of feed rate in the cleaning efficiency

The feed rate was controlled by the operator skill and it was performed after a long trail and accustoming to feed in constant feed as much as possible. The shape of the drum is highly influence in charging and discharging without additional effort of the operator. The auger type drum assists to pull the bulk of the crop immediately on the touch of the concave leap; in addition of this the inlet chute of the thresher was at the lower side of the drum. As indicated on the (Figure 11) the new 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 comparison of result among threshing units shows it has the significant difference of cleaning efficiency under 99% of confidence (Table 3).This was happened because of the construction of the concave (round or closed) type (Figure 3b). It has more threshing area of contact than the open type concave and the drum push the bulk immediately to the next part of the threshing compartment and it doesn't give time to fallen only at the inlet side of the concave, this facilitate also to have 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) to get clean *tef* seed. When the feed rate increase the cleaning efficiency decreased in the case of SG-2000 thresher, where as in the new developed thresher after a certain level the cleaning efficiency increase (Figure 11) this could happen because of the area of the concave. The total area of the open concave SG model is $0.77m^2$ and the new closed type is $1.40m^2$. The ANOVAs Table 4 indicate under 5% of probability the parameters are not highly significant for cleaning efficiency.

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	

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	

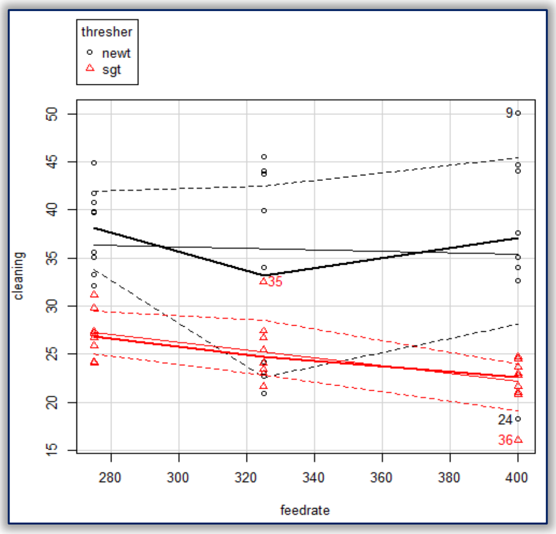

Figure 11.The effect of feed rate on cleaning efficiency of two threshing units

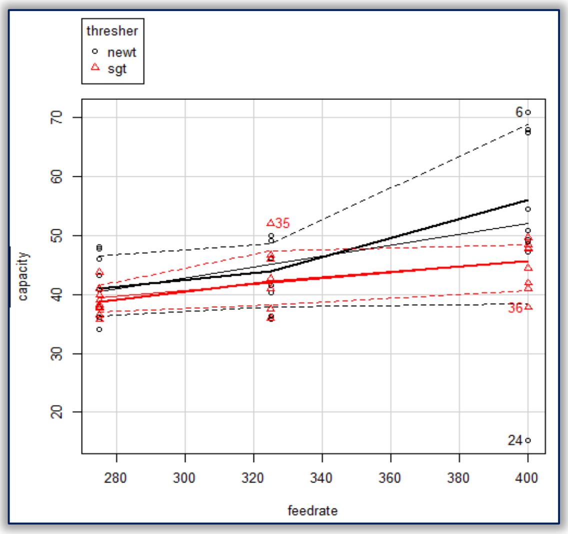

Figure 12. The effect of feed rate on capacity of two threshing units

— The effect of feed rate in the capacity of the threshing units

The capacity is directly proportional to the feed rate when the feed rate increases the capacity of both threshing units increase with minimum capacity difference (Figure 12). 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 among the two threshing units. But for both type of threshing units as indicated in the ANOVAs Table 5, the feed rate is highly significant at the level 99% confidence interval.

— The effect of feed rate on the separation efficiency

The feed rate has negative correlation with the separation of the threshing units for both two type of threshers. As indicated on the (Table 6 and Figure 13) the optimum value of the feed rate can predict around 280 and 300 kg/hr.When the feed rate increase from 275 to 325kg/hr and from 325 to 400kg/hr the separation efficiency decreased from 60.98 to 56.66% and from 37.57 to 32.02%; and from 56.66 to 55.78% and from 32.02 to 27.98% for new dveloped and SG-2000 threshing units respectively.

Table 6. ANOVA table for response variable capacity

	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	

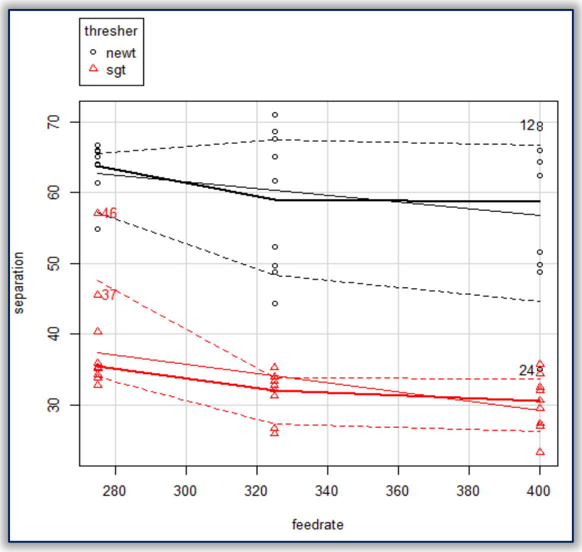

Figure 13. The effect of feed rate on separation efficiency of two threshing units

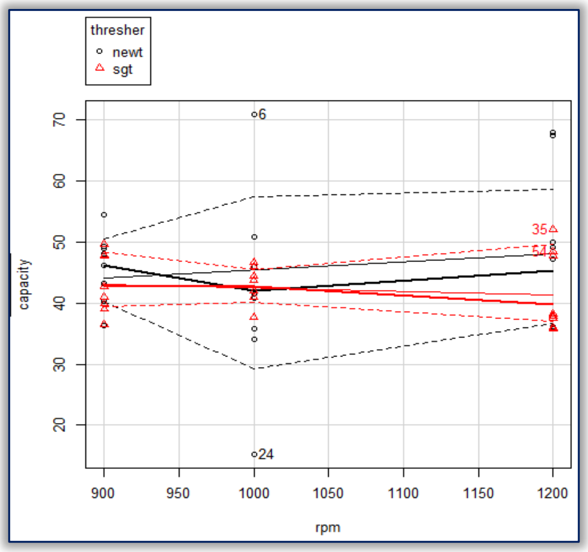

Figure 14. The effect of drum speed (rpm) on capacity of two threshing units

— The effect of drum speed (rpm) on capacity

The drum speed is corrlated for the output capacity of both threshing units, for the SG-2000 it has the negative effet and for the new developed threshing units has aminmum positive effect (Table 6). In this test at the initial speed 900 rpm the out put were good, on the 1000 and 1200rpm the capacity become decline this could be because of the tef stem propertis which has high tensile and could be rolled with the bars of the thresher drum in SG-2000 thresher.In new developed thresher after 1000rpm again the capacity shows increments, this could happened the closed type drum and concave got opportunity to rub and cut the tef stem in abetter way.In some research out puts shows the capacity has positive correlation with the drum speed (Dauda ,2015; Oni and Ali, 1986; Anwar et al., 1991; O'Ndirika, 2006; Enaburekhan, 1994).

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

The effect of drum speed on the perfromance of cleaning has the negative correlation for SG-2000 thresher and apositive correlation for new developed thresher (Figure 15 and Table 7). When the drum speed increase from 900 to 1000 the cleaning efficency decrease from 35.79 to 33.48% and when the drum speed increase from 1000 to 1200 the cleaning efficency increase from 33.48 to 43.41% for the new threshing units. This could happen beacause of the drum (auger) shape and easily pushing of bulk to the outlet.In the case of SG 2000 threshing unit, when the drum speed increase from 900 to 1000 and 1000 to 1200 the cleaning efficency decrease from 25.82 to 24.50% and 24.50 to 24.15% respectively.This could happen due to more impact /rubbing and result more breakage of the bulk in the threshing units and more mixtures passsed under the concave.

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

The effect of drum speed on the perfromance of separation rate has the negative correlation for SG-2000 thresher (Table 8) and apositive correlation for new developed thresher (Figure 16 and Table 7) When the drum speed increase from 900 to 1000 the separation efficency decrease from 60.98 to 56.66% and when the drum speed increase from 1000 to 1200 the separation efficency increase from 56.66 to 62.26% for the new threshing units. When the drum speed increase from

900 to 1000 and 1000 to 1200 the separation efficency of SG 2000 threshing unit decrease from 37.57 to 32.03% and from 32.03 to 31.25% respectively.

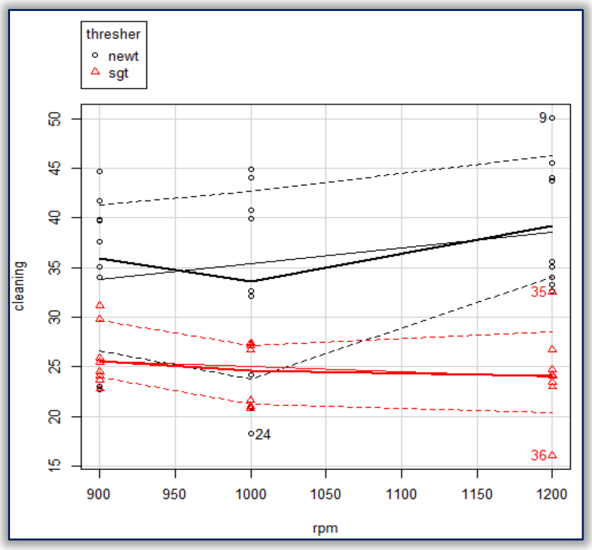

Figure 15. The effect of drum speed (rpm) on cleaning efficiency of two threshing units

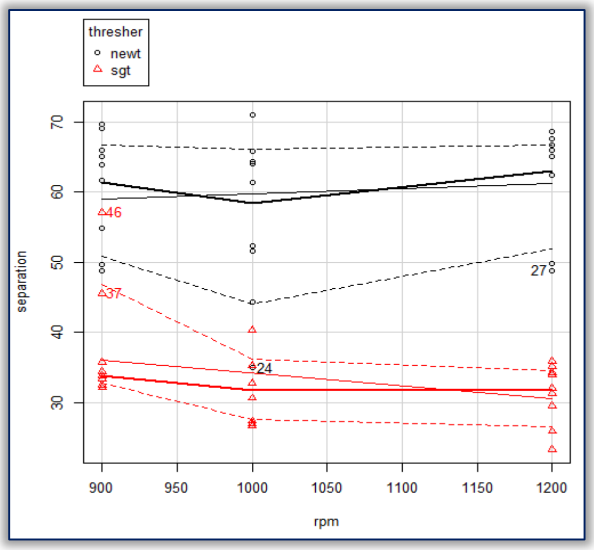

Figure 16. The effect of drum speed (rpm) on separation efficiency of two threshing units

Table 7. Summary of the correlation coefficient of variables on the performance indices for new developed threshing unit

	Capacity	Cleaning	drumspeed.rpm.	feedrate.kg.hr	Separation
capacity	1.0000000	0.66242601	1.490846e-01	4.273228e-01	0.3549236
cleaning	0.6624260	1.00000000	2.394266e-01	-4.892809e-02	0.7719110
drumspeed.rpm.	0.1490846	0.23942665	1.000000e+00	1.540297e-20	0.1052052
feedrate.kg.hr	0.4273228	-0.04892809	1.540297e-20	1.000000e+00	-0.2700074
separation	0.3549236	0.77191096	1.052052e-01	-2.700074e-01	1.0000000

Table 8. Summary of the correlation of variables on the performance indices for SG-2000 threshing unit

	Capacity	Cleaning	drumspeed.rpm.	feedrate.kg.hr	Separation
capacity	1.0000000	0.1472618	-1.616847e-01	5.543082e-01	-0.1004044
cleaning	0.1472618	1.00000000	-1.874961e-01	-6.238472e-01	0.7420157
drumspeed.rpm.	-0.1616847	-0.1874961	1.000000e+00	1.540297e-20	-0.3640085
feedrate.kg.hr	0.5543082	-0.6238472	1.540297e-20	1.000000e+00	-0.5252806
separation	-0.1004044	0.7420157	-3.640085e-01	-5.252806e-01	1.0000000

4. CONCLUSION

The performance of *tef* threshing units at the existing size of the stationary threshers were evaluated in three response variables i.e. capacity, cleaning efficiency and separation efficiency with two independent variables feed rate and drum speed. The result revealed that 45.61 and 42.30 kg/hr;35.92% and 24.85% and 59.96 % and 33.61% of capacity, cleaning efficiency and separation efficiency for new 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 and pure *tef* seed, however the study was focusing to maximize the cleaning and separation efficiency at the existing size of threshing units and obtained promising results. So, it is recommended for further study to improve the performance of the new developed threshing units by optimizing the opening of the concave holes and incorporate additional shaking sieves under the concave.

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