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Adaptation and Performance Evaluation of Engine-Driven Asella Wheat and Barley Thresher to PTO-Driven

Gosa Bekele[1*], Wabi Tafa[2], Abulasan Kebereddin[3], Ashebir Tsegaye[4], Abdisa Teshome[5] & Degefa Woyessa[6]

[1-6]*Oromia Agricultural Research Institute, Asella Agricultural Engineering Research Center, Arsi, Oromia, Ethiopia.*
Corresponding Author (Gosa Bekele) Email: gosaagem@gmail.com[*]

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ABSTRACT

Ethiopia's diverse agro-ecological zones enable the cultivation of a wide range of agricultural products. However, traditional threshing methods for crops like barley and wheat are inefficient, requiring significant labor, time, and leading to substantial post-harvest losses. To address this, the study focused on adapting a PTO-driven wheat and barley thresher developed at the Asella Agricultural Engineering Research Center. The modified thresher consists of key components, including the mainframe, feeding table, threshing unit, grain and chaff outlets, a three-point linkage, and a power transmission system. A split-split plot experimental design was employed, testing three variables: crop type (wheat and barley), drum speed (three levels of rpm), and feed rate (three levels of kg/hr), each with three replications. The study analyzed the effects of these operational parameters on threshing capacity, efficiency, cleaning efficiency, grain breakage, and grain loss. The optimal performance was achieved at a drum speed of 1000 rpm and a feed rate of 1500 kg/hr. Under these conditions, the thresher demonstrated a capacity of 586.00 kg/hr for wheat and 478.00 kg/hr for barley, with threshing efficiencies of 99.44% and 99.92%, respectively. Cleaning efficiency reached 97.50% for wheat and 95.41% for barley, while grain breakage remained low (0.46% for wheat, 1.16% for barley). Fuel consumption was measured at 0.58 and 0.62 liters per hour for wheat and barley, respectively. Overall, the findings indicate that the adapted thresher is user-friendly, mechanically simple, and well-suited for small to medium-scale farmers in Ethiopia.

Keywords: Agriculture; Cereal Crops; Post-Harvest; Wheat; Barley; Thresher; Threshing; Drum Speed; Feeding Rate; Threshing Capacity; Cost.

1. Introduction

Agriculture is the primary source of income and livelihood for most Ethiopians, serving as the foundation of the national economy. As in many African nations, this sector plays a crucial role—contributing 32.7% of Gross Domestic Product (GDP), supplying 84% of total exports, providing over 70% of raw materials for agro-processing industries, and generating employment for 73% of the workforce while sustaining 90% of the population [16].

The country's primary cereal crops such as teff, wheat, maize, sorghum, and barley cover nearly 75% of cultivated land [18]. Ethiopia ranks as the second-largest wheat producer in sub-Saharan Africa, trailing only South Africa [21], with ambitions to achieve wheat self-sufficiency and become a net exporter by 2025/26. Barley also holds a key position among Ethiopia's top four cereal crops [14].

Despite high production levels, post-harvest losses for major grains range from 15.5% to 27.2%, with threshing alone accounting for up to 6% of losses [17]. Threshing, the first critical post-harvest operation, involves mechanically separating grain from straw through applied force, influenced by factors such as impact intensity, pod orientation, and moisture content [20]. In Ethiopia, many farmers still rely on traditional threshing methods, such as animal trampling, which is labor-intensive, time-consuming, and inefficient, leading to significant grain loss.

To address these challenges, government and non-governmental organizations have introduced improved mobile threshers, including a multi-crop thresher developed by the Asella Agricultural Engineering Research Center

MJBAS PROMOTING RESEARCH & KNOWLEDGE
Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

(AAERC) [11]. Mechanical threshers offer clear advantages over conventional methods, improving efficiency, reducing labor, and minimizing losses [4]. However, performance depends on cylinder speed, feeding rate, and moisture content [6].

While AAERC's thresher originally required a 12 hp diesel engine, rising costs have made this option less affordable. Meanwhile, the government has been distributing tractors to farmers to promote mechanization. To leverage existing tractor power and reduce post-harvest losses, this study focuses on adapting a Power Take-Off (PTO) driven wheat and barley thresher, ensuring cost-effective and efficient threshing operations.

1.1. Study Objective

To adapt and evaluate the performance of Asella-driven Wheat and Barley thresher to PTO-driven.

2. Material and Methods

This study presents the research methodology employed to address the study objectives. It systematically details the materials, experimental procedures, and analytical approaches used to evaluate the adapted threshing machine. The following sections describe the research design, equipment specifications, testing parameters, and data collection methods in sequential order.

2.1. Materials and Instruments

Angle iron, sheet metal, square pipe, single and double line pulleys, bearings, steel shaft, tractor, PTO, fuel, oil, bolts and nuts, electrodes, flat iron, round bars, improved wheat and barley thresher, tractor, wheat, and barley crops were among the materials used for prototype production and performance assessments. A digital balance, a spring balance, a tachometer, a graduated fuel cylinder, a moisture meter, and a stopwatch were among the tools used for data gathering and performance evaluation.

2.2. Methods

2.2.1. Machine description and working principles

The components of the Adapted Asella wheat and barley thresher are as follows. Grain discharge unit, straw and chaff discharging unit, cleaning unit, feeding table, and power transmission unit are these parts. The steel shaft that is welded in the middle of the threshing drum is composed of rolled sheet metal. It is fastened to the drum with a spike tooth and peg. To make straw motion and biting easier, spike tooth pegs of a certain type are fastened to the threshing drum in the appropriate configuration. Through PTO, it transfers power from the tractor to the thresher via power transmission devices.

The thresher needs to be set up on flat ground in order to minimize vibration while using tractor power via PTO. Power is sent from the tractor engine to the thresher via PTO, and when PTO is operating, the crop material placed on the feeding table is forced into the drum's entrance. For threshing the crop material, a drum that rotates in a concave and receives power from the PTO is utilized. Grain and straw travel to the grain and straw outlets, respectively, while the crop is threshed. After passing through a concave fall onto the grain collector, the grain was released from the machine. Air pressure generated by the blower and systems put on the drum as a result of peg and chopper arrangements help move the straw, chaff, and undesirable debris to the straw outlet.

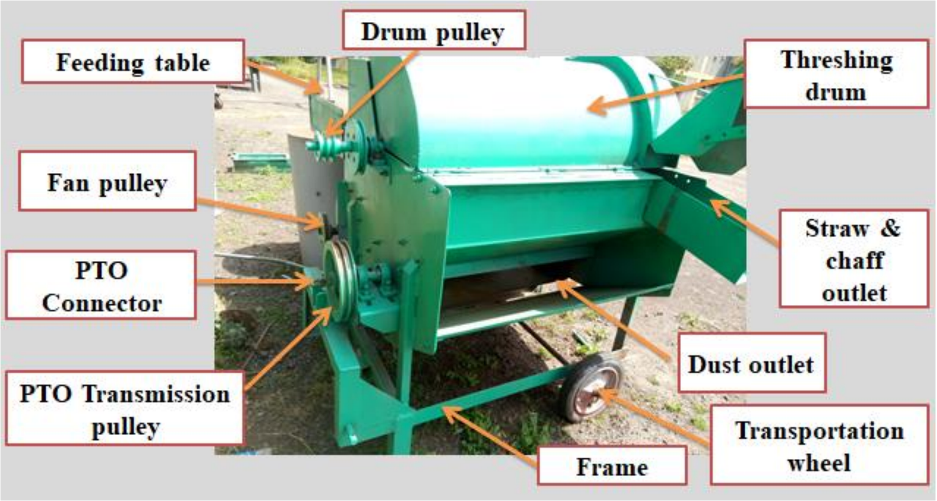

Figure 1. The main parts of adapted PTO-driven thresher

2.2.1.1. The modified parts and other machine components

(a) Threshing drum

The threshing drum is held in the concave and made from rolled mild steel sheet metal having 1.5 mm thickness on which peg and chopping devices were welded. The principal parameters of the threshing drum are the drum length, the drum diameter, the number of beaters on the drum, and the drum speed [3].

$$Q = q_o \, x \, L \, x \, M \qquad (1)$$

Where:- Q = Feed rate of thresher (kg/s), q_o = Permissible feed rate (kg/s. m) and varies between 0.35 – 0.4, L = Drum length (m), and M = Number of (rows of) beaters.

Based on the above equations, the threshing unit dimensions were modified as follows; drum diameter increased from 300 mm to 480 mm, the number of beaters also increased from 48 to 78 and 35 to 57 for peg beater and chopper respectively. From equation 1, drum length and threshing capacity have a direct relation between them so increasing drum length and diameter increases the threshing capacity of the machine.

(b) Concave

Concave is the lower half of the drum which served as the discharge through holes for the threshed crops. Concave length and clearance remain constant to 1000 mm and 15 mm respectively while its radius increased from 180.5 to 310 mm. The upper half concave was served as the cover. It was made from rolled sheet metal and served as a cover for the crop material during threshed.

(c) Fan

The air blast created by the fan pushes the straw out of the thresher. The fan of wheat and barley thresher has four blades attached to the fan shaft mounted on two bearings on each end side to allow free rotation. So, this fan will be improved based on the aerodynamic properties of the crop. The diameter and the length of the fan remain constant at 375 mm and 995 mm respectively. For agricultural applications, fan speeds are recommended to be between 450 and 1000 rpm [1].

2.2.1.2. Selection of power transmission and drive system

(a) Selection of pulley diameters

The pulleys used in the drive system were groove-type pulleys made of cast iron. Pulley diameters were selected based on the need to reduce the PTO speed to the required one. The following equation is used to determine pulley diameters.

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \qquad (2)$$

Where: N_1 and N_2 are rpm of driving and driven pulleys, D_1 andD_2 are the diameters of driving and driven pulleys. The values of D_1, D_2, and N_1 were 255 mm, 90 mm, and 540 rpm and the maximum determined value of N2 was equal to 1530 rpm.

(b) Selection of the belt

Classical V-belt and groove-type pulley arrangements were used in this work to transmit the power required by the threshing machine. The main reasons for using the V-belt drive were its flexibility, simplicity, and low maintenance costs. Additionally, the v-belt has the ability to absorb shocks thereby mitigating the effect of vibratory forces [13].

(c) Determination of belt contact angle

The belt contact angle is given by the following equation [13].

$$\varphi = Sin^{-1}\left(\frac{R-r}{C}\right) \qquad (3)$$

The angles of wrap for the smaller and larger pulleys are determined by the following equation:

$$\alpha_1 = 180 - 2Sin^{-1}\left(\frac{R-r}{C}\right) \qquad (4)$$

$$\alpha_2 = 180 + 2Sin^{-1}\left(\frac{R-r}{C}\right) \qquad (5)$$

Where: R = radius of a larger pulley, mm; r = radius of a smaller pulley, mm; α_1 = angle of wrap for the engine pulley, deg; α_2 = angle of wrap for the drum shaft pulley, deg; C = is the center distance between the two center pulleys.

Therefore, by using the above equations the determined values of φ, α_1, and α_2 were 11.60^0, $156.80^{0,}$ and 203.20^0 whereas that of the drum pulley and fan pulley connector was 3.58^0, 172.84^0 and 187.16^0

(d) Determination of belt length

The length of the belt appropriate to drive the system was calculated using the equation given below by [19].

$$L = 2C + \frac{\pi}{2}(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad (6)$$

$$L = 2*0.41 + \frac{3.14}{2}(0.255 + 0.09) + \frac{(0.255 - 0.09)^2}{4*0.41} = 1.378m$$

The closest standard length of the belt was selected from the standard table and this value was 1372 mm. Since the belt is A type of V- belt we added to the inside length of 43 so, the exact length of the v belt is equal to 1415 mm and that of the fan pulley and drum pulley was found to be,

$$L = 2*0.68 + \frac{3.14}{2}(0.175 + 0.09) + \frac{(0.175 - 0.09)^2}{4*0.68} = 1.6789m$$

Then the closest value was 1727 mm and since the belt is a B type of V- belt we added to inside length of 43 so, the exact length of the V-belt is equal to 1770 mm.

Then the exact center distance was determined by the following equation [13].

$$C = \frac{K + \sqrt{K^2 - 32(D_2 - D_1)^2}}{16} \qquad (7)$$

$$K = 4L - 6.28(D_2 + D_1) \qquad (8)$$

Where: L = belt length, m; C = center distance between pulleys, m; D_2 = pitch diameter of driven pulley, m; D_1 = Pitch diameter of driver pulley, m.

Since the calculated length of the v belt is equal to the closest standard belt the exact center distance is also correct. Therefore, the center distance was equal to 430 mm and 676 mm respectively for drum-PTO connector pulleys center distance and fan-drum pulley center distance. The speed of the belt was calculated by using the following equation [13].

$$v = \frac{\pi D_1 N_1}{60} \qquad (9)$$

$$v = \frac{3.14*0.255m*540rpm}{60} = 7.21m/s$$

This determined value was the highest for performing performance evaluation.

(e) Determination of belt tensions

To determine tensions on the tight and slack sides of the belt the following equations were used [13].

$$T_1 = T - T_c \qquad (10)$$

$$T = \sigma_{\max} a \qquad (11)$$

$$T_c = mv^2 \qquad (12)$$

Where: T_c and T= the centrifugal and maximum tension of the belts (N); T_1 and T_2 = tension in the tight and slack sides (N); σ_{max}= maximum safe normal stress (N/mm^2); a = is a cross-sectional area of the belt (mm^2); m = mass per unit length of belt (kg/m); v = is the speed of the belt (m/s).

Tensions on the tight and slack sides of the belt were estimated using the equation given below [13]:

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu \alpha_1 \operatorname{cosec} \frac{\beta}{2}} \qquad (13)$$

Where: μ = coefficient of friction between a belt and a pulley (0.25)

β = groove angle in deg. From design book = 40^0

α_1 = angle of wrap on a small pulley in rad.

According to [13], torsional moment (T_r) due to double belt and single belt tensions was determined using the following equation.

$$T_r = (T_1 - T_2)\frac{D_2}{2} \qquad (14)$$

Where: T_1 = tension on the tight side of a belt (N), T_2 = tension on the slack side of a belt (N), D_2 = is the diameter of the driven pulley (m).

(f) Shaft diameter determination

A shaft is a rotating machine element that is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. Also, transfer the power from one shaft to another through various members such as pulleys, gears, etc. These members along with the forces exerted upon them cause the shaft to bend [13]. The diameter of the threshing drum and fan shaft were determined using maximum shear stress theory.

The total bending moment was determined by using the following equation.

$$M = \sqrt{M_V^{\,2} + M_H^{\,2}} \qquad (15)$$

Where: M_V = vertical bending moment (Nm), M_H = horizontal bending moment (Nm).

According to [9]; the diameter of the threshing shaft was calculated using the theory of maximum shear stress.

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

$$d^3 = \frac{16 fs}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t T_r)^2} \qquad (16)$$

Where: - d = Shaft diameter, Ss = Allowable shear stress for the shaft ($42N / mm^2$) from design book,

K_b = Shock factor for bending moment = 1.5, K_t = Shock factor for torsional moment = 1.3,

M_b = Maximum bending moment (N. m), T= Maximum torque (N. m) and *fs* = factor of safety which is = 3 for agricultural equipment's.

Based on the above equations, the resultant bending moment of 50 Nm was calculated by considering the maximum bending moment of M_V and M_H. Also, the torque of the shaft was estimated by using Eqn. (14) finding out 38.28 Nm. As a result, the minimum diameter of the shaft was found to be 31.99 mm. Therefore, a 35 mm diameter stainless steel shaft was used for the operation of the threshing unit. Similarly, for the fan shaft, the resultant bending moment and the torque of 27.05 and 10.07 Nm were calculated and from this, the diameter of the fan shaft computed was 24.94 mm. Based on this the fan shaft of 25 mm diameter was used to carry the fan blade and to provide an optimum blowing system.

(g) Bearing selection

Bearing size can be selected by determining the maximum resultant force on it, bore size, and desired maximum lifespan. Therefore, since the diameter of the drum and fan shaft has been determined to be 35 and 25 mm, a UCP bearing of 207 and 204 were selected for the drum shaft and fan shaft [13].

2.2.2. Performance Evaluation of the Machine

2.2.2.1. Experimental design

The experimental design was a split-split plot design according to the principle of factorial experiment with three replications. The two crop types were assigned to the main plot, the three levels of threshing drum speed were assigned to the plot, and the three levels of feeding rate were assigned to the sub-sub plot. The experiment design was laid as 2*3*3 with three replications and had a total of 54 test runs (2*3*3*3 = 54).

2.2.2.2. Statistical analysis of data

The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment. Data was analyzed using statistical R software (version 3.4.3, 2017). Where the effects of the treatment were found significant, the Least Significance Difference (LSD) test was performed to assess the difference among the treatments at a 5% level of significance.

2.2.2.3. Variables and data collected

Three independent variables (crop types and machine parameters) were used during the evaluation. These were the two types of crops (wheat and barley), the speed of the threshing unit (800, 900, and 1000 rpm), and the feeding rates (900, 1200, and 1500 kg/hr).

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

A predetermined weight of each crop bundle was placed on the feeding table and then pushed into the threshing unit at the selected drum speed. The performance of the wheat and barley threshing machine was evaluated in terms of threshing capacity, threshing efficiency, cleaning efficiency, grain breakage, and grain loss.

(a) Threshing capacity (kg/hr)

The weight of grains (undamaged and damaged) threshed and received per hour at the main grain outlet was used to determine capacity. At the end of each test, the total threshed grain was collected from the main grain outlet. The threshing capacity (TC) was being calculated from the following expression [8].

$$TC = \frac{W_g}{t} \times 60\,\text{min}/hr \qquad (17)$$

Where:- TC= threshing capacity (kg/hr), W_g= Weight of threshed grain at a main outlet (kg), t = Recorded time of threshing (min).

(b) Threshing efficiency (% TE)

Threshing efficiency is the ability of the thresher that separates the grain from the straw and the stuck correctly. It was calculated according to the following equation [6].

$$\%TE = \frac{T_G - Un_G}{T_G} \times 100 \qquad (18)$$

Where: T_G = Weight of total grains input per unit time, kg; Un_G = Weight of un-threshed grains per unit time, kg.

(c) Cleaning efficiency (% CE)

It is the ability of the thresher that separate grain from the chaff and straw and was calculated according to the following equation

$$\%CE = \frac{W}{W_O} \times 100 \qquad (19)$$

Where: W = Weight of grains from the main output opening after cleaning, kg; W_O = Weight of grains and small chaff from the main output opening, kg.

(d) Broken/damaged grain (% GB)

All physically damaged/broken grains were visually observed, manually sorted, and weighed using a digital balance. Damage due to mechanical threshing was determined as the ratio of the weight of the actual damaged kernels to the weight of a sample taken.

$$\%GB = \frac{W_b}{W_s} x100 \qquad (20)$$

Where:- W_g = percentage of broken grain, W_b = weight of broken (damaged) grains (g), W_s = Weight of sample taken (g).

(e) Grain Loss (%GL)

The total grain loss percentage (GL) including both un-threshed grain losses (UGL), damage grain losses (DGL), and grain losses in straw (GLS) were calculated for the wheat and barley thresher using the following equation [5].

$$GL(\%) = UGL + DGL + GLS \qquad (21)$$

Where:- GL = Total Grain Losses, kg; DGL = Percent of damaged grain losses, %; UGL = Percent of un-threshed grain losses, %; GLS = Percent of Grain losses in straw, %.

(f) Fuel consumption

The fuel consumption was having a direct effect on the economics of the machine. The fuel consumption was measured by the refill method. The fuel tank of the tractor was filled at its full capacity and the machine was run. Finally, after the test was completed the fuel was refilled in the tank up to the top level. The quantity of refilled fuel was expressed as l/ hr.

(g) Grain-Straw Ratio

Straw grain ratio was determined by selecting five samples of wheat and barley crops bundles weighing 1 kg each and were threshed manually using sticks. Grains were separated from each sample manually and the weight of grain and straw were measured separately by using physical balance. After that, it was determined as below [5].

$$\text{Straw grain ratio} = \frac{W_1}{W_2} \qquad (22)$$

Where; W_1= Weight of straw separated from crop (g); W_2= Weight of grain separated from crop (g).

3. Results and Discussion

This study was carried out to adapt and evaluate the performance of AAERC-driven wheat and barley thresher to PTO-driven. The threshing capacity (TC), threshing efficiency (TE), Cleaning efficiency (CE), grain breakage percentage (GB), and grain Loss percentage (GL) were estimated and examined as a function of the drum speed (DS) and feed rate (FR). The results of performance evaluation obtained from the experiments conducted in the research investigation are reported and discussed in this chapter. During the experiment the grain moisture content were 14.5% and 12.5% for wheat and barley respectively while the grain straw ratio were also1:0.89 for wheat and 1:1.2 for barley crops.

3.1. The Effects of Drum Speed and Feed Rate on Performance Parameters

(a) Threshing Capacity

Table 1 show the relation between drum speed and threshing capacity in wheat and barley crops at drum speeds of 800, 900, and 1000 rpm and feed rates of 900, 1200, and 1500 Kg/hr. The maximum threshing capacity was observed to be 586 and 478 Kg at a drum speed of 1000 rpm and feed rate of 1500 Kg/hr and the minimum threshing capacity of 435 and 370.67 Kg was obtained at a drum speed of 800 rpm and feed rate of 900 Kg/hr for wheat and barley crop respectively. The threshing capacity increased from 435 to 581.33 Kg and 37.67 to 424 Kg

MJBAS PROMOTING RESEARCH & KNOWLEDGE
Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

at a drum speed of 800 rpm when the feed rate increased from 900 to 1500 Kg/hr for wheat and barley crops respectively. Similarly, at the same range of feed rate threshing capacity increased from 453 to 586 Kg and 397.33 to 478 Kg at drum speed of 1000 rpm for wheat and barley. From the table, one can be observed that as the DS and FR increased, threshing capacity also increased. The increase of grain output was increased when the feed rate was increased and the trend agreed with the results reported by [7].

Table 1. Effect of drum speed and feed rate on performance parameters of adapted PTO-driven wheat and barley threshing machine

DS (rpm)	FR (Kg/hr)	TC (Kg/hr)		TE (%)		CE (%)		GB (%)		GL (%)	
		Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
800	900	435.00	370.67	99.81	99.84	97.2	94.27	0.08	0.24	1.68	2.07
	1200	521.67	401.67	99.71	99.87	96.9	94.07	0.18	0.31	1.05	1.6
	1500	581.33	424.00	99.93	99.91	96.47	93.40	0.23	0.4	0.68	1.15
900	900	445.00	388.00	99.85	99.87	97.57	95.10	0.14	0.51	2.15	2.95
	1200	537.00	418.67	99.93	99.91	97.27	94.5	0.25	0.60	1.9	2.47
	1500	585.00	441.33	99.95	99.93	97.07	93.77	0.30	0.76	1.33	2.02
1000	900	453.00	397.33	99.83	99.85	98.87	97.43	0.23	0.82	3.07	4.18
	1200	552.00	438.33	99.92	99.89	98.33	96.07	0.39	0.91	2.3	3.5
	1500	586.00	478.00	99.94	99.92	97.50	95.41	0.46	1.16	1.85	3.03

Results of the analysis of variance (ANOVA) revealed that the feed rate, drum speed, crop type, interaction of feed rate and crop type, the interaction of drum speed and crop type, the interaction of feed rate and drum speed had a significant effect ($p < 0.05$) while the interaction of crop type, drum speed, and feed rate had no significant effect ($p > 0.05$) on threshing capacity. Table 2 and Table 3 shows the effect of threshing drum speed, feeding rate, and the combined effect of drum speed and feed rate on the machine threshing capacity.

Table 2. The main effect of drum speed and feed rate on performance parameters of adapted PTO-driven wheat and barley threshing machine

Drum speed (rpm)	TC (Kg/hr)		TE (%)		CE (%)		GB (%)		GL (%)	
	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
800	512.67^{c}	398.78^{f}	99.81^{b}	99.87^{a}	96.86^{c}	93.91^{f}	0.16^{f}	0.32^{d}	1.14^{e}	1.61^{d}
900	522.33^{b}	416.0^{e}	99.91^{a}	99.90^{a}	97.30^{b}	94.45^{e}	0.23^{e}	0.63^{b}	1.79^{c}	2.48^{b}
1000	530.33^{a}	437.89^{d}	99.89^{a}	99.88^{a}	98.23^{a}	96.30^{d}	0.35^{c}	0.97^{a}	2.42^{b}	3.57^{a}
Feeding rate (Kg/hr)										
900	444.33^{c}	385.33^{e}	99.83^{d}	99.86^{cd}	97.88^{a}	95.60^{d}	0.15^{f}	0.53^{c}	2.3^{c}	3.07^{a}
1200	536.89^{b}	419.56^{d}	99.85^{d}	99.89^{bc}	97.50^{b}	94.88^{e}	0.27^{e}	0.61^{b}	1.8^{e}	2.5^{b}
1500	584.11^{a}	447.78^{c}	99.94^{a}	99.92^{ab}	97.01^{c}	94.19^{f}	0.33^{d}	0.77^{a}	1.29^{f}	2.07^{d}
CV (%)	0.9	0.9	0.04	0.04	0.4	0.4	6.05	6.05	8.88	8.88
LSD (5%)	4.06	4.06	0.038	0.038	0.375	0.375	0.025	0.025	0.184	0.184
SEM	1.416	1.416	0.0133	0.0133	0.1308	0.1308	0.009	0.009	0.064	0.064

Means followed by the same letter (or letters) do not have a significant difference at a 5% level of probability
Where; CV=Coefficient of variation (%), LSD=List significance difference, SEM= Standard errors of means.

(b) Threshing Efficiency

The test result of feed rate and drum speed on threshing efficiency for wheat and barley has been given in Table 1. From the Table 1 for wheat crop the maximum threshing efficiency of 99.95% was obtained at the 1500 Kg/hr feed rate and 900-rpm drum speed while 99.01% of threshing efficiency for barley was recorded at 1500 kg/hr feed rate and 1000 rpm drum speed. The minimum threshing efficiency of 99.71 % and 97.69 % was obtained at the feed rate of 1200 Kg/hr and drum speed of 800 rpm and 900 kg/hr and 800 rpm for wheat and barley respectively. As the feed rate increased from 900 to 1500 Kg/hr, the threshing efficiency increased from 99.81 to 99.93% and 99.84 to 99.91% at 800 rpm drum speed for wheat and barley respectively. Similarly, for the same range of feeding rate, the threshing efficiency increased from 99.85 to 99.95% and 99.87 to 99.93% at a drum speed of 900 rpm for wheat and barley respectively. Also, threshing efficiencies were increased from 99.83 to 99.94% and 99.85 to 99.92% at a drum speed of 1000 rpm, for wheat and barley respectively. The increase in threshing efficiency due to the increase in speed may be attributed to higher energy imparted by the threshing drum resulting in better threshing of the crop material in the threshing unit. From this investigation, the threshing efficiency was increased with an increase in feeding rate at all drum speeds. This was the cause of high energy and, therefore, high compaction shearing force on the crop materials in the threshing at a higher speed.

Table 3. Effect of the drum speed and feeding rate on the performance of wheat and barley threshing machine

Drum Speed (rpm)	Feeding Rate (kg/min)	TC (kg/hr)	TE (%)	CE (%)	GB (%)	GL (%)
800	900	402.83^{i}	99.83^{cd}	95.73^{ef}	0.16^{g}	1.88^{e}
	1200	461.67^{f}	99.79^{d}	95.48^{ef}	0.24^{f}	1.33^{f}
	1500	502.67^{c}	99.92^{a}	94.93^{g}	0.32^{e}	0.92^{g}
900	900	416.50^{h}	99.86^{bc}	96.33^{cd}	0.33^{e}	2.55^{c}
	1200	477.83^{e}	99.92^{a}	95.88^{de}	0.43^{d}	2.18^{d}
	1500	513.17^{b}	99.94^{a}	95.42^{f}	0.53^{c}	1.68^{e}
1000	900	425.17^{g}	99.84^{a}	98.15^{a}	0.53^{c}	3.63^{a}
	1200	495.17^{d}	99.90^{ab}	97.20^{b}	0.65^{b}	2.92^{b}
	1500	532.00^{a}	99.93^{a}	96.45^{c}	0.81^{a}	2.44^{c}
CV (%)		0.9	0.04	0.4	6.05	8.88
LSD (5%)		4.97	0.046	0.459	0.031	0.225
SEM		1.734	0.0163	0.1602	0.0109	0.078

Means followed by the same letter (or letters) do not have a significant difference at a 5% level of probability Where; CV=Coefficient of variation (%), LSD=List significance difference, SEM= Standard errors of means.

The analysis of variance (ANOVA) revealed that drum speed and feeding rate had a significant effect ($p < 0.05$), whereas crop type and the whole remaining interaction had no significant effect ($p > 0.05$) on threshing efficiency. Table 2 and 3 shows the effect of drum speed, feeding rate, and the combined effect of drum speed and feed rate on mean threshing efficiency.

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

(c) Cleaning efficiency

The effect of feeding rate, drum speed on cleaning efficiency is presented in Table 1. The maximum cleaning efficiency of 98.87% and 97.43% was obtained at 1000 rpm drum speed and 900 Kg/hr feeding rate, while a minimum cleaning efficiency of 96.47% and 93.40% was recorded at 800 rpm drum speed and 1500 kg/hr feeding rate for wheat and barley respectively. As the feeding rate increased from 900 to 1500 Kg/hr, at a drum speed of 800 rpm, the cleaning efficiency decreased from 97.20 to 96.47% and 94.27 % to 93.40 % for wheat and barley respectively. The cleaning efficiency increased with an increase in the speed of the drum from 800 to 1000 rpm for wheat and barley. At a constant drum speed, the cleaning efficiency decreased as the feeding rate increased. An increase in drum speed increased the mean cleaning efficiency of the machine and this agrees with the findings of [10], [15], [4]. The increase of the drum speed causes an increase in blower speed, resulting in a high air blast, thereby increasing the cleaning efficiency. The decrease in the percentage of cleaning efficiencies by increasing feeding rate is attributed to the excessive wheat and barley crops in the threshing chamber.

The result of the analysis of variance (ANOVA) revealed that drum speed, feeding rate, and crop type and the interaction of crop type and drum speed had a significant effect ($p < 0.05$) on cleaning efficiency. On the other hand, the interaction of crop type and feeding rate, drum speed and feeding rate, crop type, drum speed, and feeding rate had no significant effect ($p > 0.05$) on cleaning efficiency. Table 2 and 3 shows the effect of cylinder speed, feeding rate, and the combined effect of drum speed and feed rate on mean cleaning efficiency.

(d) Grain Breakage

Table 1 show the average values of grain breakage in wheat and barley crops at the drum speed of 800 rpm, 900 rpm, and 1000 rpm and feeding rate of 900, 1200, and 1500 Kg/hr. The maximum observed breakage was 0.46 and 1.16% at a drum speed of 1000 rpm and feeding rate of 1500 Kg/hr for wheat and barley crops respectively. The minimum breakage was observed to be 0.08 and 0.24% at a drum speed of 800 rpm and all feeding rates for wheat and a feeding rate of 900 Kg/hr for barley. More grain breakage at higher speeds was due to greater impact by pegs and choppers of the drum to detach the grain from ear heads, which was reflected in the increase of breakage percentage at higher speeds. These results are similar to the findings of [12].The result of the analysis of variance (ANOVA) revealed that crop type, drum speed, feeding rate, the interaction of crop type and drum speed, interaction of crop type and feeding rate, the interaction of drum speed and feed rate had a significant effect ($p < 0.05$) whereas interaction of crop type, feed rate, and drum speed had no significant effect ($p > 0.05$) on threshing efficiency. Table 2 and 3 shows the effect of drum speed, feeding rate, crop type, and the combined effect of drum speed and feeding rate on mean grain breakage.

(e) Total Grain Loss

As it can be seen from the Table 1 the maximum grain loss of 3.07 and 4.18% was recorded at 1000 rpm of drum speed and 900 Kg/hr feeding rate for wheat and barley crops respectively. While a minimum grain loss of 0.68 and 1.15% was recorded at 800 rpm drum speed and 1500 kg/hr feeding rate for wheat and barley respectively. As the feeding rate increased from 900 to 1500 Kg/hr, at a drum speed of 800 rpm, the grain loss percentage decreased

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 3, Pages 75-90, July-September 2025

from 1.68 to 0.68% and 2.07 to 1.15% for wheat and barley respectively. Similarly, for the same range of feeding rate and at a drum speed of 1000 rpm, the grain loss decreased from 3.07 to 1.85% and 4.18 to 3.03% for wheat and barley respectively. At a constant drum speed, the grain loss percentage decreased as the feeding rate increased, while at a constant feeding rate, the grain loss percentage increased as the drum speed increased. That may be due to the increment in drum speed which leads to more grain loss by blower. This tends to agree with the results reported by [2]. From Table 2 and 3 the result of the analysis of variance (ANOVA) revealed that crop type, drum speed, feeding rate, and the interaction of crop type and drum speed had a significant effect ($p < 0.05$) on the percentage of total grain loss. Whereas their interaction of crop type and feeding rate, the interaction of drum speed and feeding rate, and the interaction of crop type, drum speed, and feeding rate had no significant effect ($p > 0.05$) on grain losses.

4. Conclusion and Recommendation

4.1. Conclusion

The threshing process is one of the important processes, which takes place after harvest. It's performed manually by animals, or mechanically. Different institutions and researchers tried to design, develop, select, modify, and evaluate many threshers for their performance. Basically, the performance of the threshing machine depends on the type of threshing operation, machine parameters, and crop characteristics. The study was aimed to adapt proper PTO-driven wheat and barley thresher.

Based on the machine's operational parameters, the performance parameters namely, threshing capacity, threshing efficiency, cleaning efficiency, percentage of grain breakage, and percentage of total grain loss were determined and the results were analyzed statistically. The effect of operational parameters on machine performance parameters shows that the maximum threshing capacity of 586 and 478 kg/hr were recorded at the combination of 1000 rpm drum speed and feed rate of 1500 Kg/hr for wheat and barley respectively. The maximum threshing efficiency and cleaning efficiency of 99.95 and 98.87%; 99.93 and 97.43% were recorded for wheat and barley respectively. The maximum grain loss and grain breakage of 3.07 and 0.46%; 4.18 and 1.16% were recorded for wheat and barley respectively. Also, the maximum fuel consumption during the threshing operation was equal to 0.58 and 0.62 lit/hr for wheat and barley at the maximum drum speed and feed rate respectively. Generally, from the study result the adapted wheat and barley thresher was more effective and efficient than the previous thresher for its capacity and suitability of operation and the obtained results can be summarized as follows:

1) The performance of the machine was affected by threshing drum speed and feeding rate.

2) Machine threshing capacity, threshing efficiency, and percentage of grain breakage increased with increasing drum speed and feeding rate.

3) Cleaning efficiency and total grain loss decreased with increasing feed rate and increased when drum speed increased and feed rate was constant.

4) The adapted and evaluated threshing machine was found to be promising and efficient in the wheat and barley threshing operation. It is simple and could be fabricated in workshops available in our country.

4.2. Future Recommendations

Further issues, which may be considered in the future study, are the following:

1) To achieve the optimum results for threshing capacity, threshing, and cleaning efficiency, it is recommended to use a combination of 1000 rpm drum speed and 1500 kg/hr feed rate.

2) It is highly recommended to work on the improvement in terms of thresher to increase its capacity.

3) It is good if the thresher is evaluated for other grain types like sorghum and Teff.

4) Demonstration and pre-scale-up of this threshing machine should be undertaken at the farm level.

5) Advance quick-change components (e.g., interchangeable sieves, concaves) to reduce transition time between crops is recommendable.

6) Simplify access to internal components for easier cleaning and maintenance, reducing operational downtime and labor costs should be advised.

Declarations

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Consent for publication

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Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of Data and Material

Supplementary information is available from the authors upon reasonable request.

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