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DESIGN, DEVELOPMENT OF FEED CONVEYOR AND PERFORMANCE EVALUATION OF AN INTEGRATED MELKASSA MAIZE SHELLER

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Abstract: The removal of stalks and husks from seeds is known as threshing. This can be performed conventionally or mechanically. One mechanical type is the Melkassa Sheller. When using it, the feeding process is labor-intensive and unsuitable for the operator. To solve this problem, the development of feed for Melkassa maize Sheller is the best solution. The developed conveyor consists of a frame, bearings, rotating belts, pulleys, side cover, and lower hopper. To determine the effect of the conveyor, the evaluation was performed by comparing manual and conveyor feed with a completely randomized design. Finally, the economic cost of the analysis was calculated. Performance evaluation in terms of shelling capacity, efficiency, seed breakage, fuel consumption, and labor requirements. The tests were carried out on a Melkassa maize sheller, maize variety (Melkasa-II), with a moisture content of 12.3 percent. The capacity of the Sheller is 7518 kg per hour, with a fuel consumption of 2.685 liters per hour when feeding with a conveyor, and 6248 kg per hour and 2.0678 liters per hour without conveyor feeding. The seed breakage during test feed with conveyor was 0.21% and 0.22% without conveyor feed. Using a feed conveyor can increase threshing capacity, reduce drudgery, save time and energy, and reduce risks.
Keywords: feed conveyor, shelling performance and economics

1. INTRODUCTION

Crop production in Ethiopia has a significant effect on the gross domestic product (GDP) and is mostly covered by cereal crops. According to CSA(2021), cereal crops are the principal crops which is covers approximately 87.42% of the total area of crop production in Ethiopia. During cereal crop production, post-harvest loss greatly affects yield. These losses occur during threshing, transportation, and seed storing processes (Abhay, 2018).

Mechanical threshing can reduce post-harvest losses and improve grain quality. According to Ahmad et al.(2019), the primary aim of mechanical threshing is to reduce the labor required for the threshing process, post-harvest losses, energy, and drudgery. However, it is challenging to shell cereal crops using the Melkassa maize Sheller. The previously available feeding operation was executed manually. It is labor intensive, time consuming, and decreases the thresher capacity. During the operation, dust was blown to the operator and exposed to the accident. To solve this problem, using mechanical feeding or conveyor feeding can reduce drudgery, simplify the feeding operation, and increase thresher performance. The aim of these studies was to solve the problem of feeding units during the threshing operation by designing, developing a feed conveyor, and evaluating the performance with an integrated Melkassa maize seller.

2. MATERIALS AND METHODS

Experimentation site

The proposed machine parts were built at the Melkassa Agricultural Research Center (MARC). The study was carried out at Ethiopia's Oromia Regional State Melkassa Agricultural Research Centre in Agricultural Engineering Research. It is located at 8° 24' 985 N and 39° 19' 529 E, with an elevation of 1550 m above sea level.

Materials

During the design and development of the feed conveyor, the main material used was Melkassa-developed maize Sheller, maize crop verity Melkasa (II) for testing performance evaluation, and for the construction of a conveyor: RHS supporting frame, ball bearings, belts, aluminum for pulleys, mild steel, angel iron, belt conveyor, and round bar.

Embodiment design of feed conveyor machine

Design feed conveyor for Melkassa maize Sheller depends on the feed rate, which is determined using equation (1).

$$Q = q \times L \times N \quad (1)$$

where, Q is the Sheller feed rate ($kg.s^{-1}$) and q denotes the permissible feed rate ($kg.s^{-1}. m.$) and from (0.35 to 0.4), L, is the length of the drum (in meters), and N is the number of beaters (in rows). According to (Belay & Fetene, 2021), the number of rows (N) is 8, the length of the drum (L) is 0.83 m, and the speed (q) is 0.375 kg/s.

$$Q = 0.375 \text{ kg/s}, \times 0.83 \text{ m} \times 8 = 8964 \text{ kg.hr}^{-1}$$

Based on the dimensions of the Melkasa maize Sheller the harvested crop's inlet.

The dimension of inlet maize Sheller was 0.34 m in width and 0.2 m in height. The inlet area was then determined using Equation (2).

$$A = w \times h \tag{2}$$

where, A, is area (m^2), W is width (m), and h, is height (m).

$$A = 0.068 \text{ m}^2$$

Power determination for feed conveyor

The conveyor is determined using Equation (3) to determine the power requirement for the drum sheller. The total power requirement is the summation of the drum power and conveyor power required to obtain the total power.

$$P = F \times V \tag{3}$$

Where: P is the power in watts, F is the amount of force required to move the material in (N), and V is the speed of the material in (m/s). The power required for a flat belt conveyor can be calculated using equation (4) based on the following data of length (m), width (m), capacity (kg/s), and height (m) using the equation developed by the motion resistance, which is equal to the sum of the weight of the conveyor and the transported mass crops (Mohammed et al.,2017).

$$W = CFL(G_g + G_b)\cos\delta + G_r + H(G_b + G_g) \tag{4}$$

where: W is the total weight of the material plus the mass of the belt in kg, C is the secondary use of the resistance factor (1.7), F is the standard conveyor (0.02), h is the conveyor height (1.5 m), Gg is the weight of the material per meter, Gb is the weight of the belt per meter, and sign plus (+) upward movement and minus (-) dawn ward movement and inclination angle, and the mass crop is 77.394 kg.

$$G_g = 77.394\text{kg} \times 1.5\text{m} = 51.5 \text{ kg/m}$$

The weight of the belt (wb) is ρ × v, where the rubber density of the belt (ρ) is 1140 kg.m-3

Width (w) the belt is equal to width of in let Sheller (w) which is 0.34 m. the thickness belt is 0.003 m and length 3m. The volume required was determined using a numerical formula by considering the top and lower covers of the belts. The volume (V) is equal to the area (A) multiplied by the length of the belt (L), which is 0.0027 m^3. The mass of the rubber belt (kg) is equal to the density of rubber multiplied by the volume, which is 3.078 kg, and G_b is the total mass divided by the belt length of 1.026 kg/m.

W= CFL (Gg + Gb) cosθ + H (Gb + Gg) = 49.05N

Determination Tension of belt conveyor

Using equation (5), the belt tension on the tight side and slack side belt conveyors was determined. From the literature review, the recommended feed conveyor 2.5 m/s (Kukhmazov & Konovalov, 2021).

$$P = (T1 - T2) \times V \sim 0.5 \text{ HP} \tag{5}$$

Where: P is the power in watts, T1 is the tight side tension in N of the conveyor and T2, is the slight side tension in N of the conveyor.

Selection of pulley diameter for feed conveyor

Using (6), the diameter of the pulley is computed. According to Hussein (2016), the recommended speed of belt conveyors is 400 rpm. The driving pulley diameter (D1) was 120 mm based on direct measurements. The maximum speed was (N1) 1000 rpm and (N2, 400 rpm.

$$N1D1 = N2D2 \tag{6}$$

where N1 is the speed of the driver, N2 is the speed of the driver, D2 is the diameter of the driver, and D1 is the diameter of the driver. If the width of the belt known, the width of the pulley (w) is assumed 25% greater than the width of the belt (Khurmi and Gupta 2005).

Selection of Belts

Belt selection was performed using Equation (7) by considering the strength of the materials. The total power required, according to Mott (2004), determines the maximum tension of the belt.

$$T = S \times A \tag{7}$$

Where: T is the maximum permissible belt stress in (N) and A is the area of the belt.

According to Król (2016), the measurement length from the inside of the table standard must be adjusted from the center-to-center pulley. The number of belts was determined using Eq. (8). The total power transmitted divided by the power transmitted by the belt represents the number of belt requirements. The power (p) transferred by the belt was calculated as (T1-T2) x V. Speed (v) calculated radius (rpm) multiplied by angular speed (ω).

$$\text{The Number of belts required} = \frac{\text{the total power transmitted (wat)}}{\text{Power transimited bt belt (wat)}} = \sim 1 \quad (8)$$

So, the V belt B-type, which has with a top width 21/32 inches are select due to easily available on the market and enough to transmit power.

Selection shaft for feed conveyor

A shaft is a power transmission machine that is calculated using Equation (9) and is based on the code (ASME) and (Khurmi and Gupta 2005).

$$d^3 = \left\{\frac{16}{\pi\tau_{max}}\sqrt{(KbMb)^2 + (KtMt)^2}\right\} \quad (9)$$

Where: D is the shaft diameter (mm), Mt is the torsional moment (Nm), Mb is the bending moment (Nm), max is the maximum allowable shear stress: MN.mm^{-2}, Kb is the combined shock and fatigue factor for the bending moment, and Kt is the combined shock and fatigue factor for the torsional moment. The calculated diameter of the shaft was (D) = 25 mm.

Bearing selection feed conveyor

The bearing selection determined using Equation (10), which is based on the life in working hours, is used on the load rating and should be sufficient to provide an appropriate mix of life and reliability (Khurmi & Gupta, 2005). This is because the bearings are not subjected to axial loading (Bhandar, 2010).

$$L_{10} = \frac{60 \text{ x } N_0 \text{ x } L_{10h}}{10^6} \quad (10)$$

Where: L_{10h}, is the rated bearing life (h) and N_o is the speed of rotation of the output shaft.

Design of supporting Frame feed conveyor

The framework supports the full weight of the feed-conveyor equipment. Equation represents Euler's theory for crippling and buckling loads under various conditions (Khurmi and Gupta 2005).

$$P_{cr} = \frac{\pi^2 EI}{(Le/R)^2} \quad (11)$$

where E is the material's modulus of elasticity (E=210Gpa). P_{cr} is Euler's critical load (N), and A is the cross-sectional area of the material (mm^2).

Working principle of the machine

A detailed feed conveyor assembly view of the machine is presented in Figure 1. The major parts components are hopper assemblies, belt drives, and other power transmission mechanisms. The 3D model of the feed conveyor based on the dimensions developed which is shown in Figure 1 below.

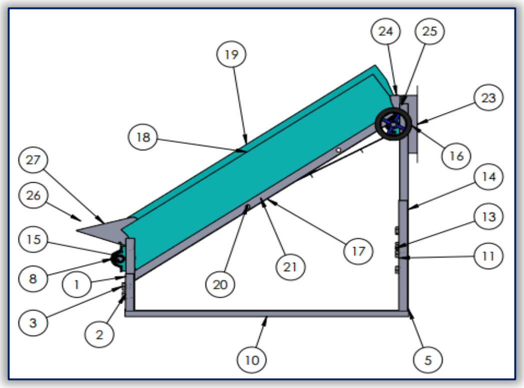

Figure 1. Assembly of the feed conveyor machine components

Table 1. Bill of material feed conveyor constructed

No.	Description of feed conveyor	No.	Description of feed conveyor	No.	Description of feed conveyor
1	Assembly lower frame support	10	Shaft of the conveyor roller	19	Top cover
2	Lower frame adjustable parts	11	Nut and bolt	20	Lower belt supporter
3	Assembly frame base parts	12	Top frame side holder	21	Lower hopper
4	Bearing	13	Height adjustable lower frame	22	Roller frame supporter
5	Conveyor belt	14	Height adjustable top frame	23	Outlet grain channel
6	Medium horizontal frame	15	Roller	24	Top frame side cover supporter
7	Lower frame attached to guide belt	16	Belt v type	25	Conveyor pulley
8	Assembly of front frame lower part	17	Side cover	26	Lower hopper
9	Assembly of front frame top part	18	Inlet supporter frame	27	Lower hoper assembly

The overall design and materials used to construct the feed conveyor were shown table above. The final manufacturing is simple way and affordable which is constructed from local available materials.

Performance evaluation with Melkassa Maize Sheller

Testing performance was conducted after the crop had been harvested and dried with moisture content ranging from 12 to 14.5 percent, making it suitable for shelling. The crop types used were Melkassa-II varieties for the maize shelling performance tested.

Moisture content during threshing and shelling operation

The moisture content was determined using equation (12) as follows.

$$M_c = \frac{Wi-Wd}{Wd} \times 100 \quad (12)$$

where M_c, is the moisture content (%), Wi is the initial weight of the sample (g), and Wd is the dried weight of the sample (g). Two samples of 100 g each were obtained from the shelled grain to determine the damaged grain (Singh, and Shojaei 2014).

Based on (Merga et al.. 2016) & (Kidanemariam, 2020), the range of speed for threshing or shelling speed for cereal crops was 500 (rpm) to 1200 (rpm) which depends on crop variety. The drum speed was 500-750 rpm. The conveyor was tested to identify the best conveyor slope and the best conveyor speed using two conveyor slopes at 20 °and 30 °, and three conveyor speeds (300, 350, and 400 rpm) with a split-plot design with three replicates were used to identify the best performance. To determine the effect of feed using the two treatments, manual feeding (MF) and feeding with the conveyor (CF) using the CRD experimental design were the feeding methods evaluated.

Statistical Analysis

Analysis of variance (ANOVA) was used to examine the different treatments (verson3.4.3, 2018). The statistical difference between the treatment means was assessed for significance at the 5% level and separated using the least significant difference (LSD).The degree of significance (P) for this relationship was determined using an F-test and an analysis of variance.

3. RESULTS AND DISCUSSION

Engineering Properties of Maize

Table 1 presents the data on the engineering properties of the maize (Melkassa II) variety prepared for testing, as shown below. The three axial dimensions (length, breadth, and thickness) measured using the Venire caliper have an accuracy of 0.01 mm. As a result, the maximum average diameter is 293 mm and the minimum is 235 mm, with an intermediate maximum diameter of 463 mm and a minimum of 342 mm. The results of the engineering properties of the selected variety are shown in the table below.

Table 2.Engineering properties of maize (Melkassa-II) data taken during testing, December 2023

Crop variety Melkassa-II	Mean ± SD	Minimum	Maximum	Shattering
Head average diameter (cm)	24.86±1.8	23.5	29.3	Medium
Intermediate diameter (cm)	38.80±4.4	34.2	46.3	Medium
Tail average diameter (cm)	24.55±6.7	15.9	34.2	Medium
Length of head (cm)	23.27±2.1	23.27	25.30	Medium
Moisture (%)	12.65± 0.4	12.2	13.2	Medium

Performance evaluation of the developed feed conveyor with an integrated maize Sheller

The feed conveyor with an integrated maize sheller and the performance evaluation are expressed in terms of shelling efficiency (%), shelling capacity and percentage of grain damage (%), fuel consumption (FC), and economic aspects determined. The feed conveyor slope and speed had a significant effect on the shelling capacity ($p \leq 0.05$).

Table 3.Result of conveyor slope and speed effects on shelling capacity

Conveyor slope (degree) x conveyor speed (rpm)		Capacity ($kg.hr^{-1}$)
20	400	7500.8 ± 1.25^{a}
	350	6899.87 ± 0.38^{b}
	300	6713.45 ± 1.01^{bc}
30	400	6621.93 ± 0.172^{bc}
	350	6614.7 ± 1.12^{c}
	300	6440.9 ± 0.85^{c}
CV (%)		1.14
$LSD_{0.05}$		0.25

Note: CV is the Coefficient of variation and LSD is the list of significance differences

Table 2 presents the interaction effect of feed conveyor slope and speed on maize sheller capacity. The highest shelling capacity of 7500.8 kg per hour was obtained for a combination of 400 (rpm) conveyor speed and a conveyor slope of 20 °, while the minimum of 6440.97 kg per hour was obtained for a combination of 300 (rpm) conveyor speed and a conveyor slope of 30 ^{0}

Figure 2 presents the testing results of the conveyor speed at 20 degree and its effects on the shelling performance. As the conveyor speed increases, the shelling capacity increases. This means that the rake's capacity to hold and transport the harvest crop for Sheller is at a suitable angle, which is resulting in an increase in shelling capacity. The conveyor slope and speed had a significant influence on the feed rate.

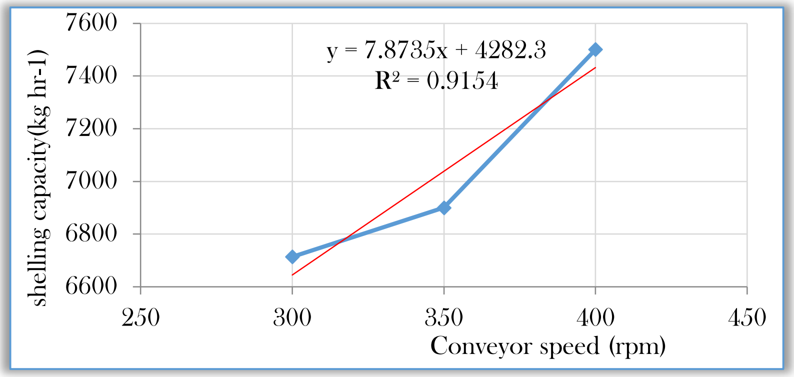

Figure 2.Graph of conveyor speed effect on shelling capacity at slope twenty degree

The effect of conveyor speed and conveyor angle effect on the shelling performance shown above and the relation of the linear regression model related feed on maize shelling capacity (kg hr^{-1}) is equal to 7.8735 SP + 4282.3 model was developed. Where, sp, are the conveyor speed (rpm), and the conveyor speed and the shelling capacity at a slope of 20 degree are linear regression equations.

Figure 3 presents the testing result of the conveyor speed and conveyor slope effects on maize Sheller machine at 30 degree. As the result when the conveyor speed increases not significant change on shelling capacity at 30 degree. The linear regression model at 30 degree in terms of shelling capacity (kg.hr^{-1}) is 1.18103sp + 5925.6 were developed. Where, *Sp*, is the conveyor speed as the conveyor speed increases from 300 (rpm) to 450 (rpm). After the conveyor speed 400rpm at 30 degree there is not significantly changed on shelling capacity.

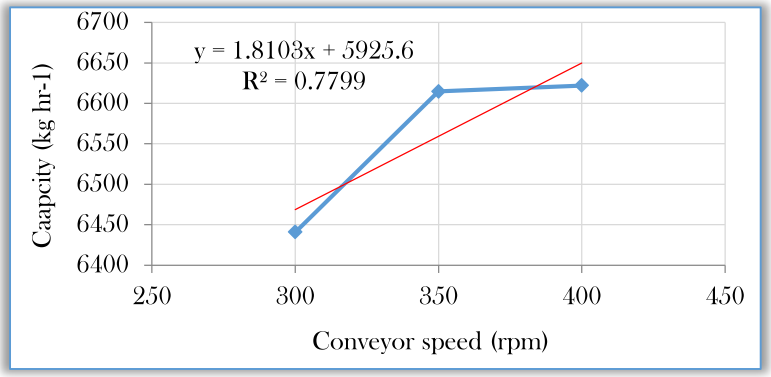

Figure 3.Graph of conveyor speed effect on shelling capacity at slope thirty degree

As a general conveyor speed and conveyor slope had significant effect on the shelling of Melkassa maize sheller machine. This finding is in agreement with (Ahmed, 2017),who reported that the capacity of shelling is a direct effect of the speed of the conveyor.

Effect of feed method on maize sheller with an integrated feed conveyor

Table 3 presents the feeding method conducted with two treatments which convectional feeding and conveyor feeding operation. The performance evaluation of maize Sheller results of feed conveyor and manual type feed had a significant influence on the Sheller capacity ($p < 0.05$). The maximum shelling capacity was 7518kg.hr^{-1} and manual feeding type is 5942kg.hr^{-1}. CV is the Coefficient of Variation and LSD is the list of significance differences.

Table 4. Effect of feeding method on Melkassa maize sheller

Treatment	Drum speed (rpm)	Capacity mean ± Std (kg.hr^{-1})
Conveyor feed type	700	7518 ± 1.07 [a]
	600	7109 ± 2.04 [ab]
Manual feed operation or convectional feeding	700	5942 ± 1.02[b]
	600	5372 ±.0 3[bc]
CV (%)		5.09
$LDS_{0.05}$		5.9

Figure 4 present the feeding effect on the shelling capacity of maize Sheller performance. As the result, the highest mean shelling capacity for conveyor feeding and manual feeding shoe on the bar graph.

The results indicated that the Melkasa Maize Sheller needed higher feed rates to work at its peak, which is difficult to achieve with manual labor. This result was similar to the results reported by (Tekeste & Degu, 2020),) also reported that the shelling capacity of manual feeding was in the range of 58 quintal per hour to 70 quintal per hour which is depending on the labor capacity to feed continuously.

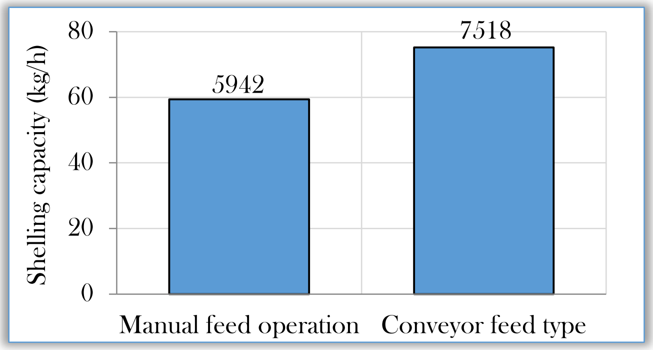

Figure 4.Mean shelling capacity of Melkassa maize sheller results

Effect of the feed on the shelling efficiency and seed breakage

The threshing efficiency of the maize shellers for the two treatments of manual feeding and feeding with a conveyor was significant ($p < 0.05$). The shelling efficiency performed at the same moisture content (12.3%), and the result is 95.02 for manual feed and 99.86% for conveyor feed. According to the same trends (Belay & Fetene, 2021), shelling efficiency is highly affected by feeding type during testing. Based on the analysis of variance, manual feed and feed with conveyor had no significant seed breakage during maize Sheller performance evaluation ($p > 0.05$). The highest seed breakage rates with conveyor feed were 0.21% and manual feed 0.22%, respectively, which was a statically not insignificant change. This trend was similar to that obtained by (Amare and Tekeste, 2017), where the mean breakage result was 0.233 ±0.105 BH661 maize variety when manual seed feeding was used.

Effect of the feed conveyor on the fuel consumption

Figure 5 and 6 presents the picture taken during performance evaluation at Awash Melkasa. The fuel consumption between the two feeding treatments using manual feeding and conveyor feeding had no significant effect ($p > 0.05$). When using feed conveyor integration, the mean fuel consumption was 3.285 liters per hour and 2.742 liters per hour was consumed during manual feeding the maximum amount of fuel consumed by the feed conveyor by the integrated Melkasa Maize Sheller was 3.021 liters per hour. Similar findings were made by (Tekeste & Degu, 2020), who determined that the fuel consumption for hand feeding of BH661 and limu maize was 3.04 liters per hour and 3.03 liters per hour respectively.

Figure 5. Picture taken during performance test feed conveyor with integrated Maize-Sheller

Figure 6.Picture of during the incorporation of drum speed with conveyor speed adjustment

Economic analysis of conveyor feed with an integration Sheller

To analyze the economics of the local experience, for shelling, the fees were 50 ETB per 100 kg. The Sheller capacity for feeding with a manual was 5942 kg/h, and feeding with a conveyor was 7518 kg/h. The mean fuel consumption when feeding with a conveyor was 3.285 liters per hour and 2.742 liters per hour consumed during manual feeding. The thresher capacity conveyor feed (TCCF) minus the Sheller capacity of manual feeding (TCMF) in kg per hour per hour and the collected data on fuel price (FP) in birr per liter differences in fuel consumption (DFC) between conveyor feed (FCCF) and manual feeding (FCMF) in liters per hour. Fuel prices (FP) are multiplied by the difference to obtain losses in fuel consumption (LFC) in Birr per hour. The difference between the seller cost (DTC) and fuel cost (DFC) is the economic benefit of using the conveyor per hour. The machine cost is 13596.20 ETB (CC) during manufacture. The assumption made was based on the agricultural implement concept: the expected life of the feed conveyor (EL) is 10 years, the feeding threshing operation conveying per year is 90 days, annual working hours (NAOHW), when the working hours are 8 in the day, salvage value (SVC): 10% capital cost, interest rate (I) 8% per annum, fuel cost (FC) per liter is 60 ETB. The cost of conveyor feed is divided into two categories: fixed and variable costs. The operational feed cost of the conveyor was estimated as the birr per hour. The fixed cost is depreciation cost (Dp) plus interest on capital (IC), the total fixed cost (ETB/h) is depreciation plus interest rate is 11.96 ETB per hour, and the operational cost is fuel cost (ETB/h). The fuel consumption of the feed conveyor was the difference between feeding with the conveyor and feeding with a manual maize Sheller (0.55 liters per hour). The change in ETB per hour is 60 ETB/liters x 0.55 liters.hr^{-1}, or 33 ETB.hr^{-1}. Therefore, the total cost of the machine (TC) is the sum of the fixed and variable costs (45 ETH/h). When the conveyor worked for 8 h, the total feed conveyor was 360 ETB/d. Feeding with conveyor minus feeding without conveyor was 1576 kg/h saved. The cost difference per day was equal to 1576 kg per hour × 8 hours per day × 50 ETB per kg, which was 6304 ETB per day. The net profit is 6304 ETB per day minus 360 ETB/day for 5,944 ETB/day. If the conveyor feed is used per day, the net profit is 5944 ETB/day. Therefore, when using a conveyor with an integrated maize seller, money and energy can be saved.

4. CONCLUSIONS

- Feeding with a conveyor had a significant impact on the dependent factor of shelling operations.
- Without changing the Sheller, only the addition of a feed conveyor can alter the threshing or shelling performance.
- The capacity of shelling is increases as the conveyor speed increases.
- The feed rate increased as the slope of the feed conveyor decreased, and the shelling capacity increased.
- Using feed conveyor results is the best option for saving energy, safe time, and reducing drudgery during threshing operations.

After these research results, the following suggestions:

- AUTOMATIC FEEDING MECHANISMS FOR ALL SHELLING AND THRESHING MACHINES CAN IMPROVE SHELLER AND THRESHER PERFORMANCE AND IT REDUCE THE DRUDGERY FOR FEEDING.
- A participatory field demonstration of the equipment at the farm level is required to generate demand, scale up, and acceptance by attaching a thresher.

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Funding statement / Data availability statement and Data sharing policy

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors Except, EIAR. Funding the work was supported by Ethiopian Institute of Agricultural Research (EIAR). The data that has been used is confidential and original. The research can be conducted with the help of EIAR, Melkassa Agricultural Engineering Research Centre, by providing budget, material workshop facilities, testing materials, and a laboratory. But to share the data due to the research discipline of EIAR is not possible or allowed.

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