DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF TEFF CLEANING MACHINE

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Abstract

In this study, the teff (*Eragrostis tef*) cleaning machine was designed, constructed, and tested. The cleaner works by the principle of air-screen cleaning which uses a fan system to remove lightweight materials and a mechanical system to remove materials with larger sizes. The machine consists of a feeding, separating and cleaning units, and power transmission components such as shafts, belts, pulleys, and bearings. The materials used for fabrication were based on the physical and mechanical properties of teff seed, design considerations like cost and availability of materials, and design analysis of machine components. The preliminary test of the machine with three feed rate and three sieve inclinations showed that the cleaning efficiency decreased from 88.72% to 69.35% for 0-degree sieve inclination, 97.85% to 73.67% for 5-degree sieve inclination, and 83.15% to 52.02% for 10-degree sieve inclination when feed rate increased from 5kg/min to 15kg/min respectively and the cleaning loss increased from 5.23% to 10.05% for 0-degree sieve inclination, 0.87% to 4.37% for 5-degree sieve inclination and 10.17% to 25.70% for 10-degree sieve inclination when feed rate increased from 5kg/min to 15kg/min respectively. The result showed that for increased feed rate, the cleaning efficiency decreased and cleaning loss increased in general.

Key Words - Teff, Seed Cleaning, Feed rate, Cleaning efficiency, Cleaning loss

1. Introduction

Teff is a cereal crop which domesticated in Ethiopia and occupies the basic part of countries' economies[1]. It is a major cereal crop used to make Ethiopian staple food called *injera* and also means for foreign currency[2]. It is a highly economic food in Ethiopia and covers 25% of cereal production. It is the second most abundantly produced grain next to maize and supports greater than 70% of Ethiopia's population's food needs[3]. Also, teff covers about a fifth of the country's agricultural areas consist of the largest area cultivated under all cereals accounting for 29.5% of the total cultivated area and 19.7% of total cereal production. Despite teff production covers the largest area of cereal crops, its yields have grown only at the rate of 1.62% per annum over the past 38 years[4]. That is because teff is mostly produced by smallholder farmers by using traditional tools[5]. This traditional method of harvesting, threshing, and postharvest handling of teff is time and energy-consuming, and usually lead to loss of seed and contamination of the product with stones, sticks, chaff, dirt, and dust[6].

As the seed is threshed and collected from the field, it is mixed with impurities like chaff, straw, weed seeds, other unwanted crop seeds, broken seeds, soil, leave, dust and dirt. These impurities must be eliminated and the seed should be cleaned and separated to provide high-quality products, for the preparation of food, and to supply uniform raw materials for industries. Grain cleaning is the operation of a post-harvest system during which contaminants mixed with grain mass are removed[7]. Teff cleaning involves different operations to remove those impurities. Traditionally, contaminants in teff seed are removed by winnowing by *layda* (traditional winnowing shovel) and *mensh* (traditional fork-like material) before separating chaff and seed on the ground until the grain is sorted from the straw and sieving to separate finer chaff and other particles from seed. This manual process is tiring and time and energy-consuming. These problems of teff cleaning led to the design of a new cleaning machine that operates for removing impurities from the seed. This current work is devoted to the design and fabrication of low-cost and affordable a teff cleaning machine in Ethiopia.

2. Methodology

Teff cleaning machine is a machine that cleanses the threshed teff seed by removing foreign materials like chaff, straw, dust, soil, and other contaminants. The process of removing is performed by both pneumatic and mechanical methods. The pneumatic method uses a fan to remove light materials by producing an air stream. In a mechanical system, sieves are used to screen out materials of large sizes. The mixture of teff seed and contaminants fed to machine through conveyor and fan driven by power source removes light materials in the first phase of cleaning. The sieve unit that is driven by the slider-crank mechanism screens out materials with large size and weight by its oscillation. The major components of the machine as shown in Fig. 1 are the feeding unit (conveyor), fan, cleaning unit, shafts, pulleys, belts, frame, and power source.

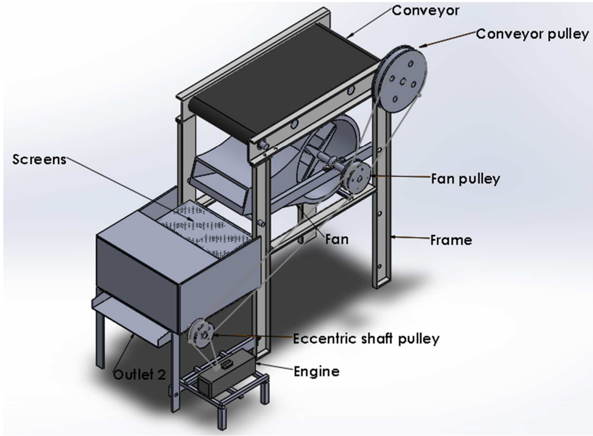

Fig. 1. Teff cleaning machine model

2.1 Design Analysis

Teff cleaning machine consists of three main units such as feeding unit (conveyor), separating unit (fan), and cleaning unit (screens and driving mechanism). In addition to these main units, it consists of power transmission components such as pulleys, belts, and belts.

2.1.1 Feeding Unit Design

Since the material in the teff cleaning process is the bulk and needs consistent feeding, it can be easily transported by the conveyor system. By considering the efficiency of production, human safety, overloading of cleaning machine, and loss of seed, a 1m long and 0.4m wide crop feeding conveyor with a belt speed of 0.25m/s were designed. According to I. A. Daniyan *et al*[8], the capacity of belt conveyor C is:

$$C = 3.6A\rho V \qquad (1)$$

Where: A= belt sectional area (m^2), ρ=material density (kg/m^3), V=belt speed (m/s).
According to Zewdu and Solomon[9], the bulk density of teff seed is 1361kg/m^3. Then, the capacity of the belt will be 136.1kg/s. The basic length of the belt is twice the twisted belt length; 2x1m=2m.

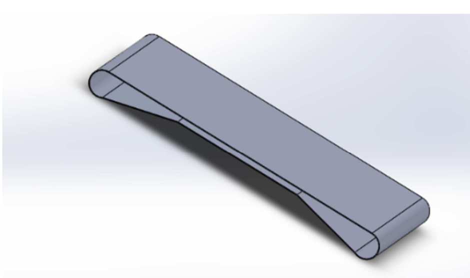

Fig. 2. Conveyor

The two end rollers with a diameter of 65mm are used to support and rotate the belt to feed the material.

2.1.2 Separating Unit Design

The design of the separation (pneumatic) system focuses on fan blower design. According to Zewdu and Solomon, the terminal velocity of teff grains ranges between 3.08 to 3.96 m/s for moisture content of 5.6% to 29.6%[9]. The terminal velocity of the air stream produced by the fan blower should be greater than the terminal velocity of light contaminants and smaller than that of grains[10]. Therefore, the terminal velocity of the air stream selected for the fan blower of the teff cleaning machine is 3.05m/s. The actual discharge of the fan blower is the product of the terminal velocity of the air stream and fan outlet area:

$$Q_a = V_t x A \qquad (2)$$

Where: Q_a = Actual flow rate of fan (m^3/s), V_t = Terminal velocity of air (m/s), A= Fan outlet area.
The fan outlet area is also the product of depth of air stream over the screen and width over which the air is required; $A = D x w$ where: D= depth of air stream over the screen (100mm) and w= width over which air is required that depends on the width of feeder conveyor (400mm) and should be wider than the feeder belt; therefore it can be 500mm. Thus, the actual flow of the fan becomes $Q_a = 0.1525 m^3/s$.
The theoretical discharge of fan given by:

$$Q_t = \frac{Q_a}{\eta} \qquad (3)$$

Where: Q_t = Theoretical fan discharge (m^3/s), η= volumetric efficiency of the fan which is usually assumed as 30%[10]. Then, the theoretical discharge of the fan becomes Q_t = 0.5m^3/s.
The dynamic head of fan given by:

$$H = \frac{V_t^2}{g} \qquad (4)$$

Where: H= Dynamic head of fan (m), V_t = Terminal velocity of air (3.05m/s), g = acceleration due to gravity (9.81m/s^2). Then, the dynamic head of the fan blower becomes H =0.95m.
According to Idris S.I *et al*[10], the power required to operate the fan is given by:

$$P_f = \frac{\rho_a Q_a g H}{\eta} \qquad (5)$$

Where: P_f = Fan power requirement (kW), ρ_a = Density of air (1.22kg/m^3), Q_a = actual flow rate of fan (0.1525m^3/s), H = Dynamic head of fan (0.95m), η= Volumetric efficiency of fan usually assumed as 30%. Then, the power required to operate the fan becomes P_f = 0.06kW.
The theoretical discharge of the fan also formulated as:

$$Q_t = \pi x d_1 x b_1 x V_1 = \pi x d_2 x b_2 x V_2 \qquad (6)$$

Where: Q_t = Theoretical fan discharge (m^3/s), d_1 and d_2 = inner and outer diameter of fan impeller respectively, b_1 and b_2 = width of the blade at inner and outer impeller diameter, V_1 $v_1$and V_2 = tangential component of the absolute velocities of the impeller at inner and outer diameter respectively.

The blade of the fan may have different shapes such as rectangular, trapezoidal, and triangular. For simplicity of manufacturing rectangular blade shape is selected for the fan blower of the teff cleaning machine with width (b_1 = b_2 =300mm).

The tangential velocity at the outer impeller diameter is twenty percent of the peripheral velocity of the impeller tip[10].

$$V_2 = 20\% \left(\frac{\pi x d_2 x N_f}{60} \right) \quad (7)$$

Where: N_f = Rotational speed of the fan shaft taken as 1000rpm. Substituting for V_2 in (6), the outer diameter of the impeller of the fan becomes d_2 =225mm.

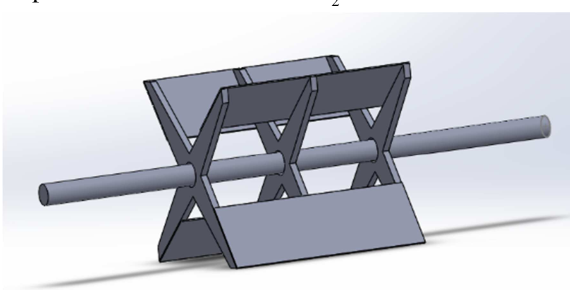

Fig. 3. Fan blade assembly

The fan housing is obtained based on the diameter of the impeller and blade size. Therefore, the diameter of the housing is 500mm, its width through which airflow is 400mm and the depth of the airflow is 100mm.

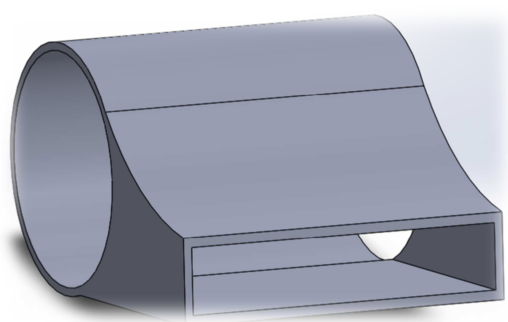

Fig. 4. Fan housing

2.1.3 Cleaning Unit Design

The cleaning unit consists of sieves and a driving (shaking) mechanism. The mechanism reciprocates the sieve attached to it. The sieve is used to separate the materials depending on their sizes, shapes, and weights by using various screens. The selection of screens for seed cleaning depends on the size and shape of the seed to be cleaned. Teff seed have oval (a prolate spheroid) shape[11] with length 1.01 to 1.27mm, width 0.59 to 0.68mm, and equivalent sphere diameter of 0.71 to 0.87mm with increasing moisture content from 5.6% to 29.6% weight base[9]. Therefore, for quality cleaning three screens such as a top with 2.5mm diameter, middle with 2.0mm, and bottom with 1.5mm diameter are designed for teff cleaning machine. According to El-Sayed *et al.,* the hole diameter of perforations on the bottom screen should be 10% more than the maximum width of the seed[12].

The inclinations of sieves depend upon the repose angle θ of teff seed that is the maximum angle at which the seed can rest on an inclined sieve without sliding down as shown in Fig. 5. Zewdu and Solomon reported that the angle of repose for teff seed is 23.74 degrees [9]. Therefore, the selected sieve inclinations for the teff cleaning design should be less than this angle to give enough time for the grain on vibrating screen to penetrate the sieve hole.

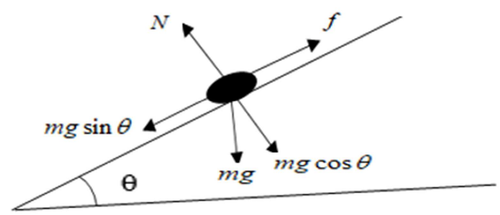

Fig. 5. Sieve inclination model with the teff grain

The screens in the cleaning unit shown in Fig. 6 were attached in a sieve shoe and driven by an offset slider-crank mechanism.

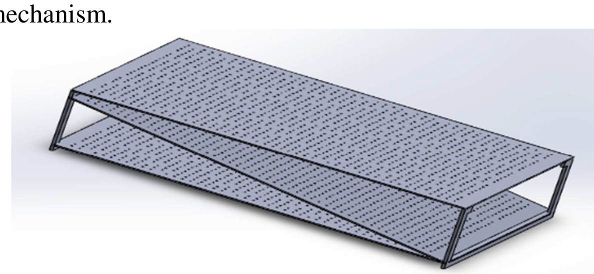

Fig. 6. Screens

2.1.4 Pulley Diameter and Belt Length

The pulleys are used to transmit power from one shaft to another using belts or ropes. For a safe velocity ratio, the pulley diameters should be carefully selected because the velocity ratio is inverse of the diameter ratio of driving and driven pulley. i.e.

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (8)$$

Where: N_1 and N_2 are the speeds of the driver and driven pulleys in rpm respectively, d_1 and d_2 are diameters of the driver and driven pulleys respectively.

There are four pulleys in the teff cleaning machine which are pulleys on the engine shaft, eccentric shaft, fan shaft, and roller shaft of feeding conveyor. The design parameters needed to determine the unknown diameters of pulleys are: the diameter of engine shaft pulley for 4hp engine is d_1= 120mm, the speed of engine shaft is N_1=1400rpm, the maximum fan shaft speed (N_f) is 1000rpm and the maximum speed of eccentric shaft (N_2) is taken as 1200rpm. Then, using (8) the diameters of eccentric shaft pulley, fan shaft pulley, and roller shaft of feeding belt pulley is 140mm, 170mm, and 340mm respectively.

The center distance of two adjacent pulleys determined as:

$$C = \frac{d_1 + d_2}{2} + d_1 \quad (9)$$

Then, the center distance of belt drive for engine shaft pulley and eccentric shaft pulley (C_1) is 250mm, the center distance for eccentric shaft pulley and fan shaft pulley (C_2) is 294mm, and the center distance for fan shaft and roller shaft of feeding belt (C_3) is 420mm.

The total length (L) of the belt may be obtained from:

$$L = \frac{\pi}{2}(d_1 + d_2) + 2C + \frac{(d_1 - d_2)^2}{4C} \quad (10)$$

Then, the total length of belt needed to transfer power from engine shaft to eccentric shaft (L_1) becomes 908.81mm, length of belt from eccentric shaft to fan shaft (L_2) becomes 1072.50mm, and length of belt from fan shaft to roller shaft of the conveyor (L_3) is 1648.5mm.

2.1.5 Shaft Diameters

The diameter of three shafts such as eccentric shaft, fan shaft, and roller shaft used in teff cleaning machine was determined by using shear stress due to twisting moment on the shaft[13]. It is given by:

$$d = \sqrt[3]{\frac{16T_e}{\pi \tau_s}} \quad (11)$$

Where: T_e =equivalent twisting moment on shaft, τ_s= maximum shear strength of shaft material.

The material selected for the shaft design of the teff cleaning machine is a low carbon steel (1006). Table. 1 shows the mechanical properties of the selected material for shaft design[14]. The maximum allowable shear stress is the lower value of eighteen percent of ultimate tensile stress and thirty percent of yield strength[10][13]. Thus, the maximum allowable shear stress of the shaft material is 51MPa.

Table 1

Mechanical Properties of Shaft Material

No	Properties	Values
1.	Tensile strength (MPa)	300
2.	Yield strength (MPa)	170
3.	Poison's ratio	0.27-0.3
4	Elongation (%)	30

The power transmitted by the belt is given by:

$$P = (T_1 - T_2)V \quad (12)$$

Where: T_1 and T_2 are tensions in the tight and slack sides of the belt, V is the peripheral velocity of the pulley,

The ratio of tension in tight and slack side of the belt is given by:

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta \quad (13)$$

Where: μ = the coefficient of friction between belt and pulley can be taken as 0.3 for rubber belt, θ= angle of wrap is determined by:

$$\theta = 180 - 2\left[\arcsin\left(\frac{d_2 - d_1}{2C}\right)\right] \quad (14)$$

Thus, the tension on the tight and slack sides of the belt by using (12) and (13) are 564.23N and 224.80N.

The torque (T) transmitted by the belt is given by:

$$T = (T_1 - T_2)r \quad (15)$$

Where: r is the radii of pulley

Thus, torque is transmitted by eccentric shaft 23.76Nm, fan shaft 28.85Nm and roller shaft 57.11Nm.

The bending moment (M) on the shaft due to the tensions of the belt:

$$M = (T_1 + T_1) * C \quad (16)$$

Where: C is the center distance between two adjacent pulleys. Thus, the bending moment on the eccentric shaft is 198.26Nm, the fan shaft is 231.98Nm and the roller shaft of the conveyor is 365.89Nm.

The equivalent twisting moment on shaft (T_e) given by:

$$T_e = \sqrt{T^2 + M^2} \quad (17)$$

Thus, the equivalent twisting moment on the eccentric shaft is 199.68Nm, the fan shaft is 233.76Nm, and the roller shaft 370.32Nm

The diameter of shafts by using (11) becomes: eccentric shaft 30mm, fan shaft 30mm and roller shaft of conveyor is 35mm by taking upper significant digit approximates.

2.2 Power Requirement Evaluation of Machine

2.2.1 Power required by cleaning unit

According to Idris *et al*[10]: the power required by a cleaning unit with a shaking mechanism is given by

$$P_c = \frac{W_s * N * 2y}{4500} + \frac{2u * W_s * N * 2x}{4500} \quad (18)$$

Where: P_c = Power required by cleaning unit, W_s = Weight of sieve components along with cleaning material (0.1183kN from previous sections), u= Coefficient of friction of moving components (0.5 maximum coefficient of friction for teff grain with steel surface from), N = Speed of driving pulley (1200rpm), x and y= horizontal and vertical displacements of sieve respectively (x=y=10mm). Then, the power required by the cleaning unit becomes $P_c = 1.262kW$

2.2.2 Power required by separating unit

The power required to operate the fan was evaluated (5) and P_f = 0.06kW.

2.2.3 Power required by feeding unit

According to Daniyan *et al*[15], the power required by conveyor belt to transfer material is evaluated as:

$$P_b = \frac{T_b * V}{1000} \tag{19}$$

Where: T_b = Steady-state belt tension on pulley (788.31N) from previous sections, V = the conveyor speed (0.25m/s). Then, the power required by the conveyor to transport material for teff cleaner is $P_b = 0.20kW$.

Then, the total power required by the machine is given by:

$$P_T = P + 10\%P \tag{20}$$

Where: P_T -total power to run the machine, P-the sum of power required in each system unit; feeding system, fan, and cleaning unit and 10%P-power loss due to friction. Then, the total power required by the machine becomes 1.70kW (2.30HP).

2.3 Fabrication of Machine

Fabrication of metal is the process of changing raw materials to machines and structures by using various machines. Teff cleaning machine fabrication involves the construction of its components by using designed values of dimensions with various materials in the workshop. To reduce cost and increase affordability, machines available in the existing workshop and locally available materials are used in the fabrication process. Table. 2 shows a list of materials used in the fabrication process of the teff cleaning machine and their specifications.

Table 2

List of Materials Used for Fabrication of Machine

SI. No	Parts	Material type	Specifications
1	Frame	Mild steel (rectangular hollow bar)	Length:1500mm, Width: 600mm Height: 1000mm Cross-section: 60mm*40mm
2	Conveyor	Textile	Length: 1100mm, Width: 500mm
3	Shafts	Mild steel (circular solid bar)	Diameter: 30mm and 35mm
4	Pulleys	Cast iron	Diameter: 140mm, 170mm, 340mm
5	Screens	Steel wire mesh	Length: 300mm, Width: 600mm Hole diameters: 2.5mm, 2mm and 1.5mm
6	Fan blade	GI sheet metal	Length: 100mm, Width:300mm
7	Fan housing	GI sheet metal	Diameter: 500mm
8	Chaff outlet	GI sheet metal	Width:300mm, Length: 100mm
9	Grain outlet	GI sheet metal	Width: 600mm, Length 100mm

Fig. 7. Teff cleaning machine fabricated

2.4 Performance Evaluation of Machine

The performance of the teff cleaning machine was evaluated by using two operation parameters such as feed rate and sieve inclination. Two performance parameters evaluated in the process are cleaning efficiency and cleaning loss with governing equations[16]:

$$CE = \frac{W_1}{W_T} * 100\% \tag{21}$$

$$CL = \frac{G_0}{G_1} * 100\% \tag{22}$$

Where: CE is cleaning efficiency, CL is cleaning loss, W_1 is the weight of cleaned seed in kg, W_T is the total weight of sample in kg, G_1 is the weight of seed at the input in kg, and G_0 is the weight of seed at the chaff outlet in kg.

To analyze and synthesize the data from an experiment, 150kg of threshed teff sample was taken from a field of threshing and divided into three test samples of 5kg, 10kg, and 15kg weighing with the mass balance to conduct tests for each sample. Each test sample was fed into the feeding conveyor of the feeding system to feed the machine uniformly in one minute. For the automatic feeding conveyor, feeding was controlled by changing the quantity of mixture over it. Three variations of sieve inclinations such as 0-degree, 5-degree, and 10-degree were adjusted by the changeable inclined frame which was connected to the sieve shoe. In this case, about 15 tests were conducted. Cleaned teff seed from grain outlet for each test was collected in a plastic sack and weighed with mass balance and the result was recorded. This was used to determine the cleaning efficiency of the teff cleaning machine.

The chaff and straw separated were collected from the chaff and straw outlet of the cleaning unit and the fan outlet of the separating unit and added into the sack. The collected chaff and straw were weighed with mass balance and the result was recorded. All the chaff and straw collected from the outlets and materials captured coming off the back of the machine were processed and cleaned manually in a controlled environment to quantify grain and materials other than grain. Cleaned grain separated from the chaff and captured material was weighed with mass balance and the result was recorded. This was used to determine the cleaning loss of the teff cleaning machine.

3. Result and Discussion

3.1 Factors Affecting Cleaning Efficiency

3.1.1 Feed rate:

Fig. 8 shows the effect of feed rate on cleaning efficiency at different sieve inclinations. It was found that by increasing the feed rate from 5kg/min to 15kg/min, the cleaning efficiency of teff cleaner decreased from 88.72 to 69.35% respectively at no sieve inclination (0^0). The cleaning efficiency of teff cleaner decreased from 97.85 to 73.67% for a similar feed rate at a sieve inclination of 5^0. The cleaning efficiency of teff cleaner also decreased from 83.15 to 52.02% for a similar feed rate ate sieve inclination of 10^0. The cleaning efficiency of teff cleaner decreased by increasing the feed rate. The main reason for decreasing efficiency is increasing load intensity on the sieve when the feed rate increases. The overload of sieve by increased feed rate closes sieve perforations and this, in turn, decreases the performance of the cleaning unit[17]. Abayneh reported that the thick layer made on the sieve surface by increased feed rate is the main reason for the decrease in cleaning efficiency that is because the closing of perforations of the sieve by materials on its surface can hinder the flow of grain through it[18]. El-Sayed *et al,* found that the thick layer formed on the surface of the sieve is the main factor for the decrease of cleaning efficiency when the feed rate increases[12].

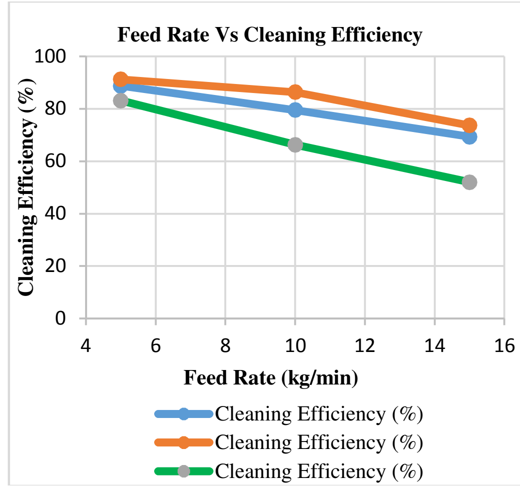

Fig. 8. Effect of feed rate on cleaning efficiency of teff cleaning machine for sieve inclination of 0, 5, and 10 degrees.

3.1.2 Sieve inclinations:

The inclination of the sieve is another operational parameter that affects the cleaning efficiency of the machine identified to study the performance of the teff cleaning machine. Fig. 9 illustrates the effect of sieve inclination on the cleaning efficiency of the teff cleaning machine. It was found that by increasing sieve inclination from 0^0 to 5^0, the cleaning efficiency of the teff cleaning machine increased from 88.72 to 97.85% respectively for a feed rate of 5kg/min. The efficiency of the teff cleaning machine decreased from 97.85 to 83.15% by increasing sieve inclination from 5^0 to 10^0 for a similar feed rate. For the 10kg/min feed rate, the cleaning efficiency increased from 79.50 to 86.35% when sieve inclination increased from 0 to 5 degrees and decreased from 86.35 to 66.30% when sieve inclination increased from 5 to 10 degrees. The reason behind the increase and decrease of cleaning efficiency by increasing sieve inclination is that when the inclination of the sieve slightly increases from horizontal, the flow of contaminants over the sieve surface is good enough to remove them but at a high inclination, the teff seeds were lost with contaminants through discharge. Salawa.S.Hanna *et al.* reported that the plugging effect of sieve holes at low inclinations which results in allowing some contaminants to move out with grain as the main reason for the decrease in cleaning efficiency of the cleaning machine[19].

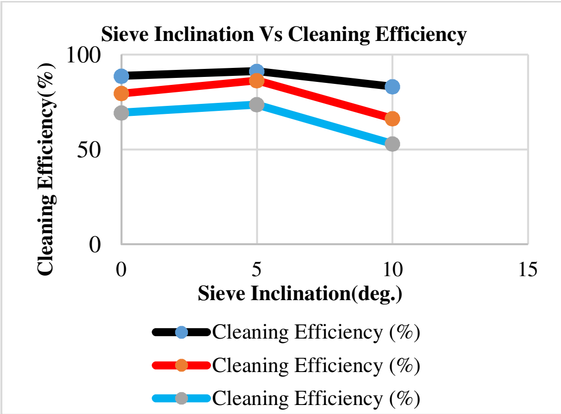

Fig. 9. Effect of sieve inclinations on cleaning efficiency of teff cleaning machine for feed rates of 5, 10, and 15kg/min

3.2 Factors Affecting Cleaning Loss

3.2.1 Feed rate:

The effect of feed rate on cleaning loss of cleaner is illustrated in Fig. 10. When feed rate increased from 5kg/min to 15kg/min, it was found that cleaning loss of teff cleaning machine increased from 5.23 to 10.05% for 0-degree inclination of sieves. The cleaning loss increased from 0.87% to 4.37% by increasing the feed rate from 5kg/min to 15kg/min for 5- degree inclination of sieves. The cleaning loss increased from 10.17 to 25.70% by increasing the feed rate from 5kg/min to 15kg/min for 10- degree inclination of sieves. In general, when the feed rate increase, the seed loss increase for all sieve inclinations. The main reason for the increase in cleaning loss with increasing feed rate is the closing of sieve perforations by increased intensity of load on the sieve surface. Simonyan and Yiljep[17] reported that matting on a sieve with impurities due to load intensity on the sieve surface during increased feed rate increases the cleaning loss.

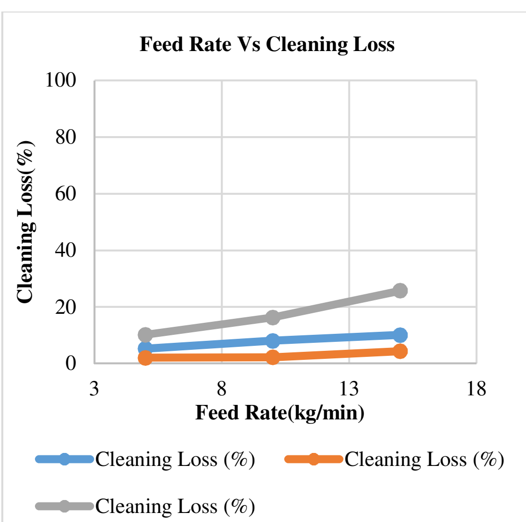

Fig. 10. Effect of feed rate on cleaning loss of teff cleaning machine for sieve inclination of 0, 5, and 10 degrees.

3.2.2 Sieve inclinations:

Fig. 11 presents the effect of inclinations of sieve on cleaning loss of teff seed cleaner. It was found that the cleaning loss decreased from 5.23% to 0.87% for increased sieve inclination from 0 to 5 degrees for a constant feed rate of 5kg/min. The cleaning loss increased from 0.87 to 10.17% for a similar feeding rate when sieve inclination increased from 5 to 10 degrees. The cleaning loss also decreased from 8.03% to 2.20% when sieve inclination increased from 0 to 5 degrees and increased from 2.20% to 16.28% when sieve inclination increased from 5 to 10 degrees for 10kg/min feed rate. Generally, the cleaning loss slightly decreases for an increase of sieve inclination from 0 to 5 degrees and increases for further increase in sieve inclination. The reason for decreasing cleaning loss for an increase in sieve inclinations is when inclination increases slightly, there is a good flow of seeds through sieve holes and creates a suitable condition for removal of impurities through chaff discharge. However, increasing sieve inclination further approaching to repose angle of teff seed results in the loss of more seed with materials other than grains through chaff discharge. El-Sayed *et al*[12], reported that when sieve inclination increased further, the time remaining for grain to flow through the sieve hole decreased and this might decrease cleaning efficiency and increases cleaning loss because some of the seeds were removed with contaminants through chaff discharge.

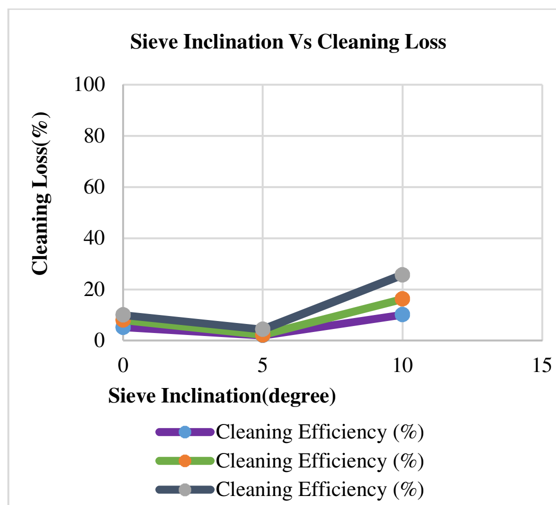

Fig. 11. Effect of sieve inclinations on cleaning loss of teff cleaning machine for feed rates of 5, 10, and 15kg/min

4. Conclusion

Teff cleaning is the process of removing impurities like chaff, straw, dust, soil, and weed seeds from the seed. The process is tiring, time-consuming, and energy overriding. Teff cleaning machine that works in the principle of both pneumatic and mechanical cleaning is designed, fabricated, and tested to solve the process problem. The cleaner consists automatic feeding unit (conveyor), a separating unit (fan), a cleaning unit (set of vibratory screens), and power transmission components such as pulleys, shafts, belts, and bearings. The physical and mechanical properties of teff seed, cost, and availability of material, and loads on machine parts were the main considered factors in the design and fabrication of the teff cleaning machine. The cleaning efficiency of the cleaner decreases with increasing feed rate and its maximum value recorded was 97.85% for 5- degree sieve inclination with a 5kg/min feed rate. The cleaning efficiency slightly increases with increasing sieve inclination from 0 to 5 degrees and decreases for sieve inclinations greater than 5 degrees. The cleaning loss increases with increasing feed rate and its minimum value recorded was 0.87% for 5-degree sieve inclination with a 5kg/min feed rate. Generally, the teff cleaning machine works more efficiently as feed rate decreased and sieve inclination slightly increased up to 5 degrees. Thus, the optimum operating parameters of the cleaner are 5kg/min feed rate and 5-degree sieve inclination with a recorded maximum cleaning efficiency of 97.85% and minimum seed loss of 0.87%. The successful development of the teff cleaning machine is expected to reduce the seed loss, required time, and energy consumption associated with the traditional teff cleaning method and therefore, increase the productivity of teff seed.

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