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Original Research Article

Design and Fabrication of Screw Conveyor Unit of a Maize Post-Harvest Handling Plant

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Abstract

A screw conveyor is an important means of transporting grains from one location to the other, especially for the loading of maize into silos for storage from the shelling system. Hence, a 100 kg/hr. maize screw conveyor was designed and fabricated. The machine conveyed shelled maize from a developed maize sheller to a silo. The major component parts of the machine include the frame, rotor shaft, and the power transmission system. The machine was tested by varying the maize moisture content into four levels: 16%, 18%, 20%, and 22%. A moisture level of 16 % resulted in the highest conveying efficiency of 99.52 %, while a moisture content of 22 % resulted in the lowest conveying efficiency of 31.56 %. The recovery efficiency ranged from 64.5% to 99.8%. A moisture content of 16% yielded the highest conveying efficiency of 99.82%, while a moisture content of 22% yielded the lowest conveying efficiency of 64.51%. With the decrease in moisture content level, both the conveying and recovery efficiency have increased. The development of this machine will reduce post-harvest loss, increase production, and utilization.

Keywords: Conveyor, maize, moisture-content, screw

INTRODUCTION

The grass *Poecea* family includes maize (*Zea mays L*). It ranks as the world's third-largest cereal crop. However, the majority of this maize is used to manufacture corn ethanol, animal feed, and other maize products like corn starch and corn syrup, so only a small portion of it is consumed directly by humans (Deobley, 2004). According to Foley (2019), maize has surpassed the production of wheat and rice in many parts of the world, according to Foley. Maize is a major component of millions of Nigerians' diets. Flower mills, brewers, confectionaries, and animal feed makers all use it as a versatile and industrial crop (IITA (2009). Jeffery (2014), reported that harvesting, drying, dehusking, shelling, transporting, storing, and milling are only a few of the unit activities that maize, like other agricultural materials, goes through before it reaches the threshold for human consumption. Handling (conveying) and storage are two of the most essential unit actions that influence the quantity and shelf life of an agricultural product. A range of equipment is used to convey agricultural materials. The type of material to be transported, as well as the nature of the application, influence the type of conveying method. Agricultural materials might be granular, powdered, fibrous, or a combination of all of these. Materials are transported by using mechanical, inertial, pneumatic, and gravity forces. Conveyors that rely primarily on mechanical forces include screws, belts, and mass. Screw conveyors are a popular way to transport farm produce and are also used as a mode of transportation. They are highly effective conveying devices for free-flowing or nearly free-flowing bulk solids, providing good throughput control and environmentally friendly solutions to process handling challenges because of their simple shape, high efficiency, low cost, and low maintenance requirements (Hemad et al. 2020). Screw conveying is recommended for efficient grain conveyance into silos. Grain can be loaded into silos for storage using either manual or engine-powered machinery, primarily in underdeveloped countries. Manual methods are time-consuming, inefficient, and incapable of handling large quantities of grain. Small and medium-scale farmers may find the mechanical technique of loading grain into silos, such as a mounted or trailer-mounted screw conveyor, too costly in terms of handling and maintenance, as well as complex to handle. As a result, a screw conveyor that may be coupled to a sheller for convenient collection and conveyance to the silo is desired. The goal of this work is to present the design, fabrication, and testing of a maize conveyor unit for a maize post-harvest system.

Materials and Methods

2.1 Materials

The materials used in the construction of the maize screw conveyor include the following: mild steel sheet of 2 mm, angle iron of 2 inches, a 2 hp electric motor, bearing, pulley, belt, mild steel rod.

2.2 Design Consideration

The following parameters were considered in the design of the machine in order to satisfy its functional requirements: availability of material; strength and rigidity; ease of operation; cost; ease of maintenance; and portability.

Component Parts of the Machine

The machine was developed to have the following components as shown in Plate I, and Figures 1 to 3.

1. Frame

   The machine frame was made of 2-inch angle iron. It gives support and rigidity to the machine while in operation. It has a dimension of 820 x 230 mm.
2. Hopper

   To allow the maize grain to flow into the conveying chamber, the hopper is trapezoidal in shape. Its measurements are 270 mm x 220 mm x 130 mm.
3. Grain discharge

   The grain outlet was constructed from 2 mm mild steel sheet with dimensions of 50 mm X 50 mm and was installed at the end of the screw to allow for simple grain drop into the silos. Its dimensions are 210mm x 95mm.

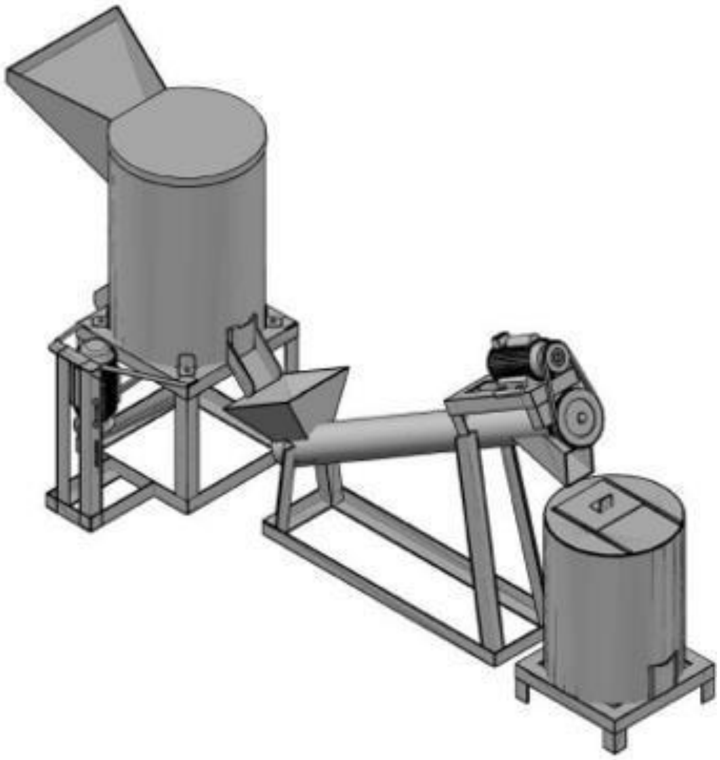

Figure-1: AutoCAD drawing of the post-harvest processing plant

Plate-I: The developed conveyor and a metal silo of the post-harvest processing plant

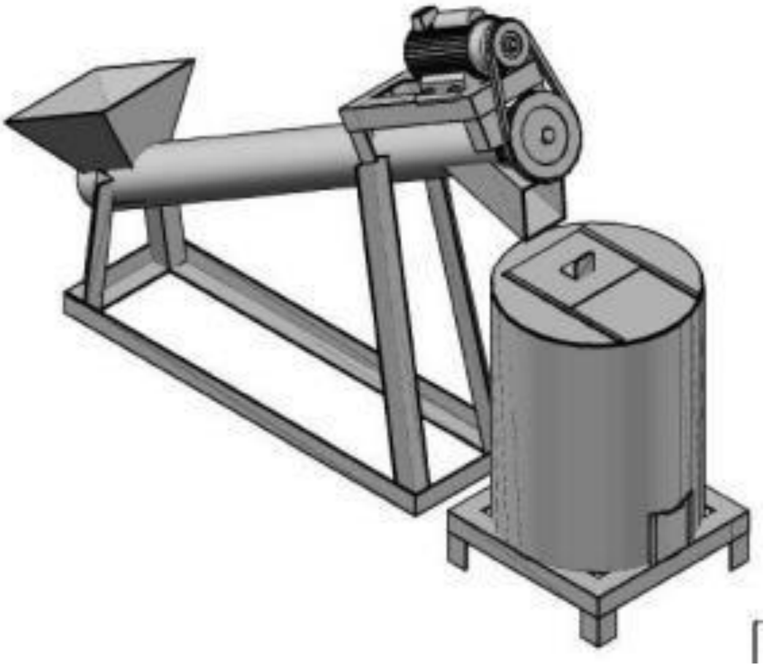

Figure-2: The conveying system with metal silo

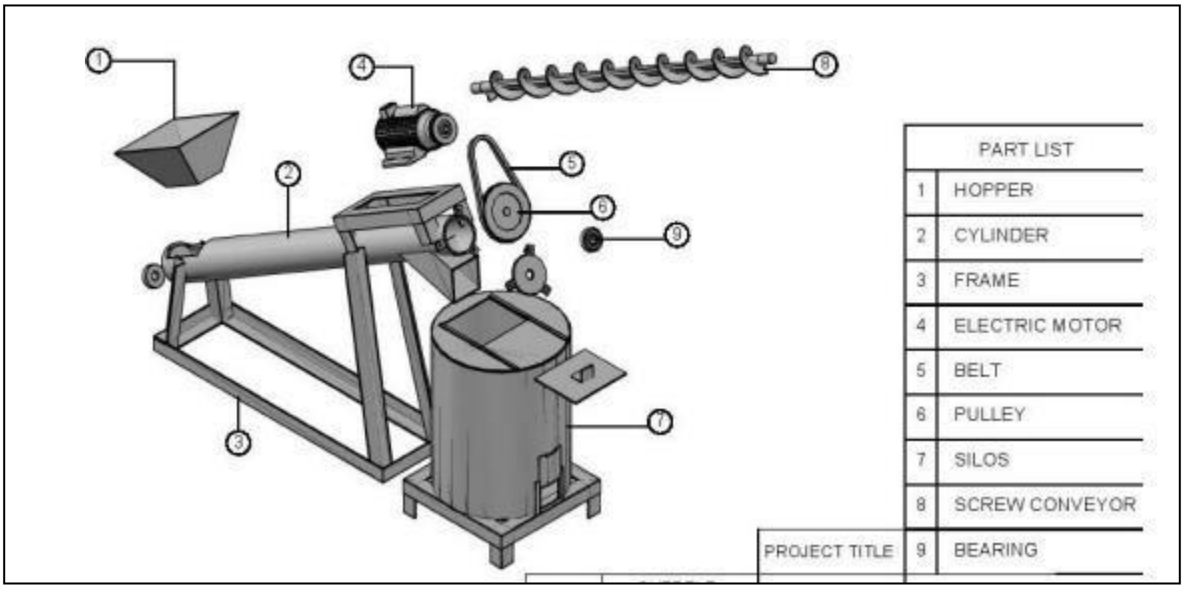

Figure-3: Exploded view of the conveying system with metal silo

Design analysis of machine components

Fundamental design analysis and calculations were used to determine and select materials of appropriate strength and size for the machine component parts.

i. Maximum mass of grain to be conveyed in a batch

The maximum mass of grain that may be conveyed at one time is crucial in determining the machine's power requirements. The mass of grain conveyed per batch was determined using an equation reported by Gana a*et al.*, (2016).

$$M_b = \frac{M_d \times T_b}{T_d \times N_d} \qquad (1)$$

Where, M_b is the mass of maize to be processed per batch (kg), M_d is the mass of maize to be processed in a day (kg), T_h is the time required to process one batch (min), T_h is the time required to process in an hour and N_d is the number of operational hour per day (hour)

ii. The conveyor designs

The shaft's design was focused on determining its diameter in order to ensure enough strength and rigidity when the shaft is transmitting power during operation and under load.

iii. Bending control

The shaft's bending stress was calculated using a formula provided by Khurmi and Gupta (2005) and is given as.

$$\sigma_B = \frac{32BMd}{\pi(d^4)} \qquad (1)$$

Where σ_B is the bending stress (N m-2), BM is the bending moment (N m); *d* is the shaft diameter (mm), π is constant.

iv. Bending moment

According to Olanrewaju et al. (2017), the bending moment can be calculated using the formula in Equation 4 and is given as

$$BM = \frac{ql^2}{8} \qquad (4)$$

Where, BM is the bending moment, q is weight of the shaft and l is the length of the shaft (m)

v. Torsional control

According to Khurmi and Gupta (2005), the angle of twist can be calculated as follows:

$$A_{tw} = \frac{T \times L}{G \times T} \qquad (5)$$

$$T = \frac{2T \times J}{D} \quad (6)$$

$$J = \frac{\pi(d^4)}{32} \quad (7)$$

$$T = \pi \times J \times \frac{(d^4)}{\sigma \times D} \quad (8)$$

Where, A_{tw} is the angle of twist, T is the Torque or torsional moment (N m), L is the length of the shaft (m), G is the modulus of rigidity of the shaft (N m-2), T is the torsional moment, J is the polar moment of inertia of the cross-section area about the axis of rotation (Nm-2), J is the maximum shear stress (according to ASME code is 53 × 106 N m-2), π = 3.142, d is the diameter of the shaft (m);

vi. Driving power of the motor

According to Ruina and Pratap (2010), the motor's driving power can be calculated as given in Equation (9);

$$P = Q \times g(L_v \times K_\text{i} \pm H)K \quad (9)$$

Where P is the driving power of the motor (watt), Q is the capacity of the auger (kg s-1), K_i is the coefficient of friction for grains (ki ranges between 2.2-2.7), K is the overloading coefficient (k = 1.05-1.2); L_v is the length of the conveyor (m), H is the perpendicular height (m) g is the acceleration due to gravity (9.81 m s-2)

vii. Driving force of the conveyor

If the conveyor is to function, the angular moment must be proportionate to the angular force, which must be greater than the required driving force. Ruina and Pratap (2010) suggested the following formula for estimating the angular force;

$$F_\text{W} = \frac{2M_\text{W}}{d_\text{i} tan(a+b)} \quad (10)$$

Where, F_W is the actual angular force, Mw is the angular moment, d_i is the diameter of screw where the bulk of the materials moves (m); Q = Pitch angle, R = 23°; B = Frictional angle for the whole screw (°).

From

$$F = tanB \quad (11)$$

$$B = tan^{-1}F \quad (12)$$

Where F is the coefficient of friction (F = 0.32-0.58)

viii. Angular momentum

The shaft's angular momentum was calculated as described by Olanrewaju et al. (2017) and is presented in Equation (13);

$$M_\text{W} = \frac{q_m}{2\pi n} \quad (13)$$

$$q_m = \frac{Qs}{V} \quad (14)$$

$$V = S \times \pi \quad (15)$$

Where, M_W is the angular momentum for the shaft, q_m is the weight of the materials to be transported (kg m-1) and is given as Equation (14), n is the number of screw rotation and is taken according to the conveyor materials for dense (Coarse) material. Where, n = 0.8-1.5, V is the velocity of the auger (m s-1), S is the pitch of the auger (m s-1)

ix. Magnitude of the driving force

The magnitude of the driving force was calculated as reported by Olanrewaju et al. (2017), and is given as;

$$F_0^l = q_m(L_v \pm H)f \times g \quad (16)$$

Where, F_0^l is the magnitude of the driving force, L_v is the length of the conveyor (m), H is the vertical height (m), f is the coefficient of friction, g is the acceleration due to gravity (m s-2).

Performance Evaluation of the Machine

The machine's efficiency in conveying and recovering data is used to evaluate its performance.

Conveying Efficiency

The machine's conveying efficiency was computed according to Zareiforoush *et al.* (2010) and is presented as;

$$E_{cf} = \frac{M_c}{M_T} \times 100 \qquad (17)$$

Where, E_{cf} is the conveying efficiency (%), Mc is mass of the maize conveyed (kg), M_T is the totalmass of the maize (kg).

Recovery efficiency

The recovery efficiency is calculated as a percentage of the total mass of the grains that are fractured or damaged compared to the total mass fed into the conveyor. According to Gana et al. (2016), it is calculated and expressed as;

$$R_{EF} = \frac{M_F - M_D}{M_S} \times 100 \qquad (23)$$

Where, R_{EF} is the recovery efficiency (%), M_F is the mass of the maize fed into the conveyor (Kg), M_D is the mass of the damage maize (Kg).

Results and Discussions

Results

The screw conveyor was created, tested, and evaluated. Table 1 shows the machine's testing results. The table showed that conveying efficiency ranged from 31.50 to 99.52 percent.

Table-1: The result obtained from the trials conducted on different speed of the machine.

Moisture content (%)	Mass conveyed (g)	Mass not conveyed (g)	Mass maize grounded & conveyor (g)	Mass of maize grounded inside the conveyor (g)	Conveying Efficiency (%)	Recovery Efficiency (%)
16	995.2	4.8	1.8	0	99.52	99.82
18	994.8	5.2	5.2	0	99.48	99.74
20	524.5	475.5	126.2	148.2	52.4	72.56
22	315.2	684.8	168.5	186.4	31.5	64.51

A moisture level of 16 % resulted in the highest conveying efficiency of 99.52 %, while a moisture content of 22 % resulted in the lowest conveying efficiency of 31.56 %. The recovery efficiency ranged from 64.5% to 99.8%. A moisture content of 16% yielded the highest conveying efficiency of 99.82%, while a moisture content of 22% yielded the lowest conveying efficiency of 64.51%.

Discussion of result

Effects of moisture content on masses of maize

Figure 4 shows that the mass of maize conveyed at 16 percent and 18 percent m.c content was the highest, at 995.2 and 994.8 g, respectively, while the mass conveyed at 20 percent and m.c content was the lowest, at 524.5 and 315.2 g, respectively.

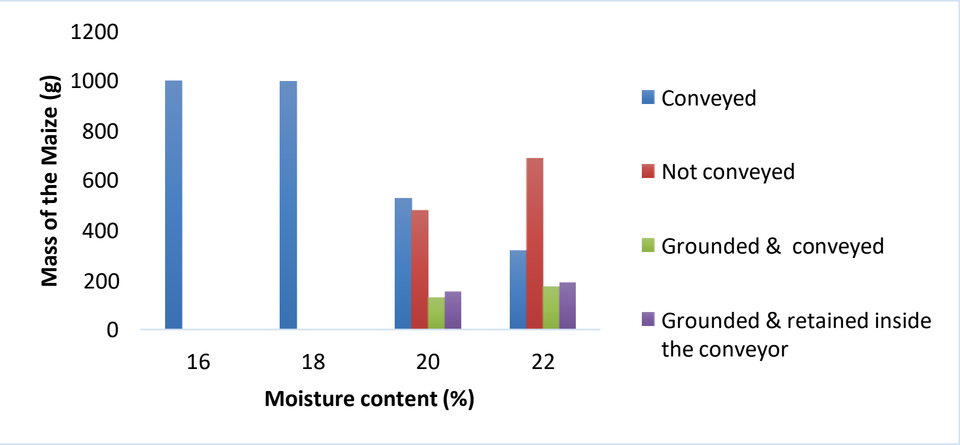

Figure-4: Effects of moisture content on masses of maize

Between the ranges of moisture content, there is a significant change in the amount of material conveyed. This could be due to the maize adhering together on the inner surface of the conveyor casing when the moisture content is between

20% and 22%. The cohesiveness between the materials and water molecules is insignificant with decreasing moisture content. This was consistent with the findings of a previous study by Jung *et al.* (2018), which indicated that the moisture content of particular agricultural materials affected their flowability. Teunou et al. (1999) also found that the high moisture content of food powders reduced their flowability due to water cohesion between powder particles.

Effects of moisture content on the conveying efficiency

Figure 5 shows that as the moisture level decreased from 22 percent to 18 percent, the conveyance efficiency increased significantly from 31.5 percent to 99.48 percent, and then remained approximately constant at 99.52 percent with a further decrease in moisture content of 16 percent. This could be due to the conveyor's inability to resist the movement of the drier materials. This supported the findings of Landillon et al. (2008), who found that wheat particles with low moisture content had a significant impact on flowability and cohesive properties. The flowability and cohesion properties of the material are affected by the moisture content because water molecules act as plasticizers on the material components.

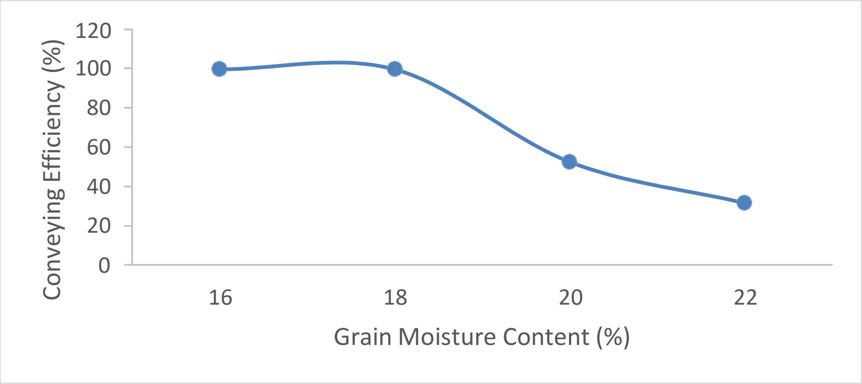

Figure-5: Effects of moisture content on masses of maize

Effects of moisture content on the recovery efficiency

Figure 6 indicates that when moisture content declined from 22% to 18%, recovery efficiency improved substantially from 64.51 percent to 99.74 percent, then remained nearly constant at 99.82 percent, with a further 16 percent decrease in moisture content. This could be due to the maize's increased softness with an increase in moisture content, making it easier to rupture. This was in line with the findings of Gana et al. (2014), who found that the rupture force of soya beans decreased as moisture level increased (10.9 to 20.5 percent) from 197.47 to 89.47 N (54.69 percent decrease), corn decreased as moisture level increased (12.4 to 20.5 percent) from 266.67 to 170.23 N (36.17 percent decrease), and sorghum decreased as moisture level increased (11.3 to 20.6 percent) from 187.23 to 187.23. For all the grains, the lower rupturing force was achieved with higher moisture concentrations. Etim et al. (2021) found that the force required to crack the seed and the energy required to break on both axes of the seed decreased as the moisture level increased. Oduma et al. (2016) reported that the rupture force of African Oil Bean seed decreased with an increase in moisture content, while the seed was observed to deform more with an increase in moisture content. As such, the recovery efficiency decreases as the rupturing of the maize increases with an increase in moisture content.

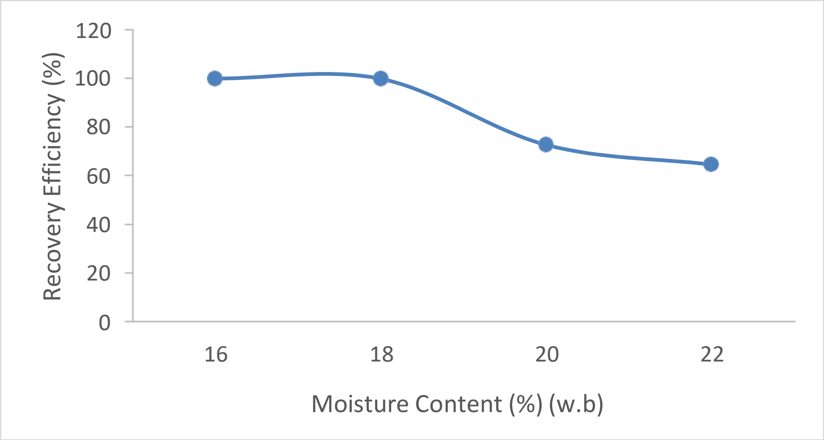

Figure-6: Effects of moisture content on the recovery efficiency

CONCLUSION

The screw conveyor was primarily designed and fabricated to eradicate drudgery involved in the indigenous method transporting maize from the shelling system to the silos. The performance evaluation gave the machine the efficiency of 95%. This was achieved with very low cost of productions which promote timely conveyance of maize grains from the shelling system into the silos, reduces drudgery and increase work rate. Therefore, due to appropriate design consideration and adequate material selection to specification, the difficulties in manual loading of maize grain into silos shall be overcome, thereby preventing wastage and damages. This will also minimize the high loss of labour incurred in manual loading.

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