# Design and fabrication of a screw conveyor

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**Abstract:** Grain transportation from one location to another is exigent. Several disadvantages are associated with grain transportation, especially manual loading into trailers and silos. The need for a grain handling equipment became pertinent; hence, this study designed and fabricated a simple and medium size auger aimed at upward conveyance of grains into a silo. The conveyor was fabricated from local materials considering the physical properties of the selected grains, the techno-economic properties of the machine. The conveyor is powered by an electric motor through a V belt connection. Tests were run on the conveyor using common granular materials like maize, sorghum and gari at 13% moisture content. The angles of test considered were 0°, 15°, 30°, 45°, and 60° for each grain. It was found capable of loading an average size silo of 2.68 $m^3$ in 15 minutes. The conveyor has an efficiency of 99.95% and average output capacities of 407.05, 282.4 and 263.1 kg $h^{-1}$ for maize, 450.2, 350.5, 263.0 kg $h^{-1}$ for sorghum and 460.0, 365.3, 310.0 kg $h^{-1}$ for gari at corresponding angles of inclination of 0°, 30° and 45° respectively. The conveyor is easy to operate with minimal technical know-how.

**Keywords:** grain, conveyor, auger, materials handling

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## 1 Introduction

Grain handling equipment is mostly used to transport grains from one location to another. The four types most commonly used for industrial and farm applications are belt, bucket, pneumatic and screw conveyors. Conveyors play an important role in the handling of agricultural materials. The high productive capacity of modern farms has created a real need for handling agricultural products in a rapid and efficient manner. The pitchfork and shovel are being replaced by power conveying equipment. Proper selection of power conveying equipment makes it possible to integrate component parts into a smooth, efficient and functional materials handling system. There are several methods used to convey agricultural materials. The selection of conveying method greatly depends upon the nature of application and on the type of material to be conveyed. Agricultural materials may be granular, powder, fibrous, or a combination of these.

A screw conveyor consists of a circular or U-shaped tube which a helix rotates. Grain is pushed along the bottom of the tube by the helix; thus the tube does not fill completely. Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. They are used in many bulk materials handling applications ranging from agriculture (i.e. conveying grain from storage bins to transport vehicles, mixing grain in storage, and moving grain in a bin to a central unloading point), chemicals, pigments, and food processing. They are very effective conveying devices for free flowing or relatively free flowing bulk solids, giving good throughput control and providing environmentally clean solutions to process handling problems because of their simple structure, high efficiency, low cost and maintenance requirement. They are not practical for high capacity or long transport distances due to high power requirements. Screw conveyors vary in size from 75 to 400 mm in diameter and from less than 1 m to more than 30 m in length (Hemad et al., 2010; Owen and Cleary,

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2009; Labiak and Hines, 1999).

The physical characteristics of the material to be handled should be considered before selecting an appropriate conveying device. In particular, the following properties are relevant for agricultural products: moisture content, average weight per unit volume, angle of repose, and particle size. Grain flow rate, distance, incline available space, environment, and economics influence conveyor design and operating parameters.

Aremu (1988) reported that Oliver Evans (an inventor of screw conveyor) gave general attention to material handling. His research revealed that about 30% of labour in food manufacturing is expended on food material handling. Henderson (1974) claimed that material flow requisite determines possible conveyors usages. This upswung to another development of various devices of conveying equipment with classification: pneumatic conveyor, chain conveyor, screw conveyor, bucket elevator, gravity conveyor, belt conveyor, powered roller conveyor, and non-powered roller conveyor. A screw conveyor with the housing diameter of 15.5 cm, screw diameter of 13 cm, screw shaft diameter 3.5 cm, and a length of 150 cm was constructed by Hemad et al. (2010) for experimental purpose. Their results revealed that the specific power requirement of the conveyor increased significantly with increase in screw diametric clearance and screw rotational speed. The net power requirement of the conveyor significantly increased as the screw rotational speed increased; whilst the value was found to decrease with increasing the screw clearance. As the rotational speed of the screw conveyor increased, the actual volumetric capacity increased to a maximum value and further increase in speed resulted in reduction in capacity. The volumetric efficiency of the screw conveyor decreased significantly with increasing the screw diametric clearance and screw rotational speed. Ahmad et al. (2014) designed and developed a tractor power take-off (P.T.O.) powered conveyor belt lift. During operation, the conveyor belt acts normal to the longitudinal tractor axis, while the tractor P.T.O. transfers power to the gearbox of the conveyor system. The angle of inclination of the conveyor i.e. gradient is adjustable through a hydraulic cylinder actuated by the hydraulic output of the tractor. The linear velocity of the conveyor is adjusted through a pulley carrying wedge-shaped belts. The conveyor belt is 5 hp, and can also be actuated through mechanical/electrical motors with lower horse powers.

Perry engineering is a company that develop a range of grain handling equipment to include chain and flight conveyors, belt and bucket elevator for agricultural produce, specifically grain. They have a capacity 750 kh $m^{-3}$ and can contain about 30,000 tonnes of wheat. They can be operated at an inclination angle that is between 45° to 90°. Frank King is another company that builds products for every agricultural application. Their grain handling equipment includes backsaw auger, conventional auger, drive-over hopper, utility auger and unloading auger. Their products are available in different models that are simple, safe, more efficient and versatile.

Moreover, Balami et al. (2013) developed and tested an animal feed mixing machine having a vertical auger conveyor with a diameter and pitch size of 0.145 m and 0.1 m respectively. It has a mixing efficiency of 95.31% attainable in 20 minutes. Aseogwu and Aseogwu (2007) overviewed agricultural mechanization and its environmental management in Nigeria. They iterated in their study that managing the technical/engineering inputs into agricultural production as expected to satisfy some societal demands on agriculture which part of them is ensuring proper handling, processing and storage of farm produce to minimize postharvest losses through the use of conveyors that transport milled and threshed grains into silos.

Daniyan et al. (2014) designed a material handling equipment, precisely a belt conveyor that was 3-roller idlers for crushing limestone. Their design preference were the size, length, capacity and speed, roller diameter, power and tension, idler spacing, drive type, angle and axis of rotation, and pulley arrangements. Their study was able to generate design data for industrial uses in the development of an automated belt conveyor system which was found to be fast, safe and efficient.

Undisputedly, manual loading of grains into trailer and silo has its associated disadvantages, a mounted or trailer type of auger could be introduced for loading grains. Considering the economics of a trailer or mounted type of auger, which are expensive in terms of fuel, man labour and maintenance, not also available in small/medium scale; this study designed and fabricated a simple and medium size auger aimed at conveying grains upward into a silo. The design and construction is expected to enhance handling of agricultural products during postharvest operations.

## 2 Materials and methods

### 2.1 Design consideration

Factors considered in the design of this machine were cost, availability of the materials, rigidity and vibration stability, durability and strength of the metallic material selected to ensure corrosion and wear resistance, portability of the machine and the techno-economic status of the intended users. Also, the necessary properties of agricultural materials considered were: the physical and thermal properties of the grains to be conveyed.

### 2.2 Description of the machine

The motorized screw conveyor consists of a worm auger, cylindrical housing, standing frame, hopper, pulley, power source clamp and V-belt for power transmission. The discharge point is at the upper end of the system where the materials conveyed are discharged. Figure 1 is the isometric and orthographic view of the machine while Figure 2 is the realistic picture.

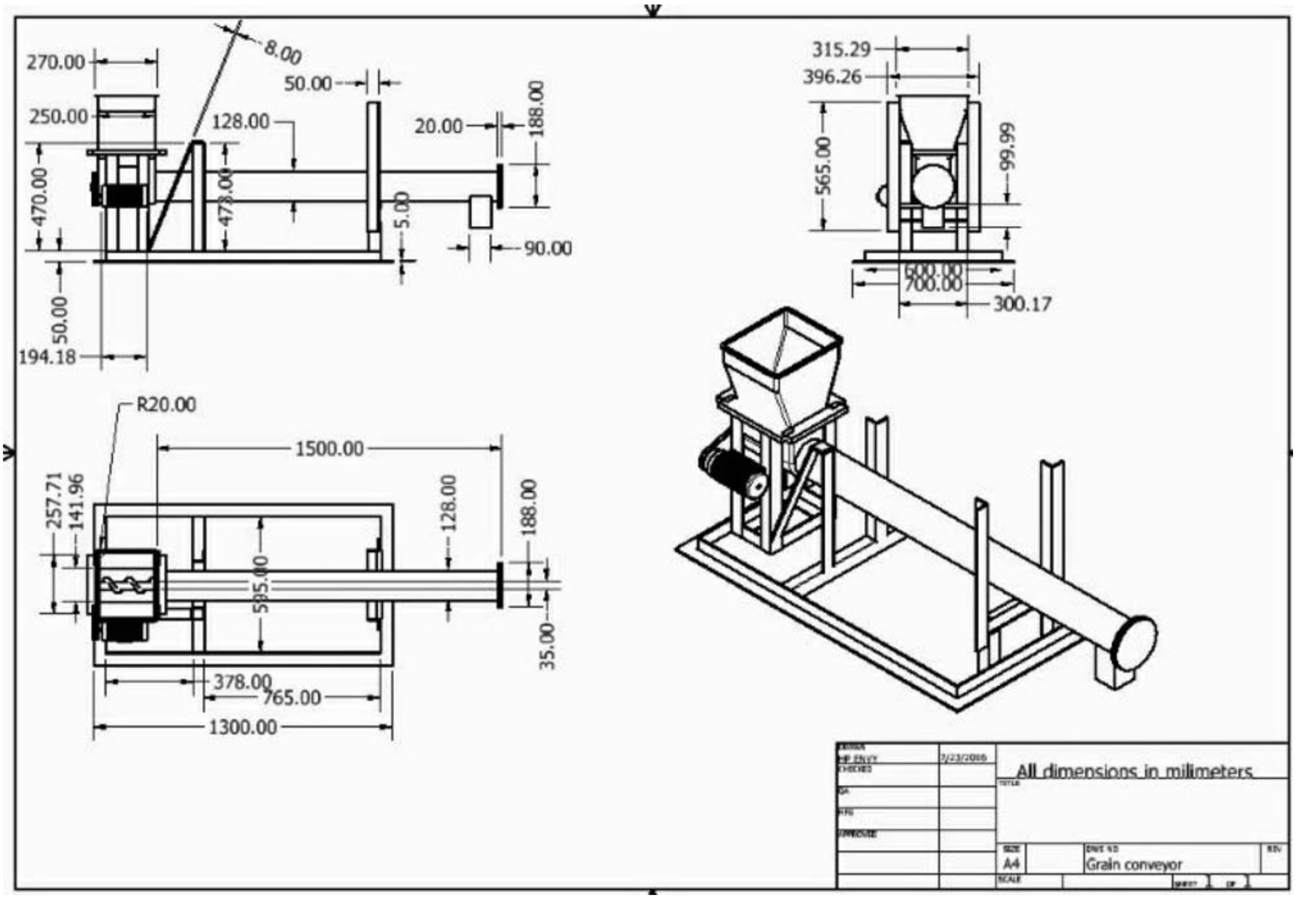



Figure 1 Isometric view of the screw conveyor

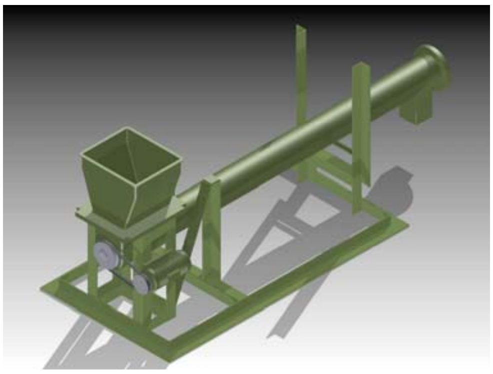


Figure 2 Realistic picture of the machine

### 2.3 Principle of operation

Due to economic consideration, the machine was designed to load a trailer/silo with average size of 2.68 $m^3$ within 15 minutes with the help of an operator. The granular materials to be conveyed are fed into the hopper at the lower end (when at an inclined position), the materials are then moved through the driven transmission via an electric motor positioned at the feeding end by the rotational effect of the auger and discharge the materials at the upper end through the outlet port. An adequate clearance between the auger blade and the housing (Barrel) was considered in the design to avoid clogging and breakage of grain kernels. A V-belt and pulley was designed for the transmission components to ensure appropriate operational speed of conveyance. For effective operation, the materials to be conveyed are expected to be at safe moisture level to prevent clogging which usually hinder the performance of the transmission unit and the electric motor.

### 2.4 Design calculations

Essential design calculations were done in order to determine and select the strength and size of the conveyor components. This was done with the aid of the results and established formulae in the design analysis.

### 2.5 The shaft

The design of the shaft was based on the determination of its diameter, so as to ensure satisfactory strength and rigidity when the shaft is transmitting power during operation and under loading condition.

### 2.6 Bending control

The bending stress "$\sigma_b$" of the shaft was calculated using Equation (1) (Khurumi and Gupta, 2004) for hollow shaft:

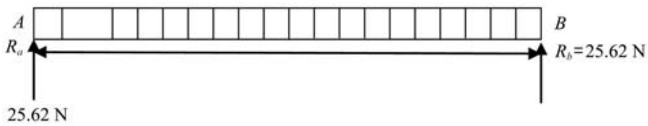
$$\sigma_b = \frac{32BMd_0}{\pi(d_0^4 - d_i^4)} \quad (1)$$

where $\sigma_b$ = bending stress (N m$^{-2}$); $BM$ = bending moment (N m); $d_o$ = outside shaft diameter (mm); $d_i$ = inside shaft diameter (mm); $\pi$ =3.142 (constant).

To obtain bending moment "$BM$"

$q$ = 2.14 kg m$^{-1}$ = 21.0 N m$^{-1}$

$l$ = 2440 mm




For uniformly distributed load (UDL)

If reaction at $A$=$R_a$ and at $B$=$R_b$

$$R_a + R_b = ql \quad (2)$$

where, $q$ = weight of the material; $l$ = length of the shaft.

$$ql = 21.0 \times 2.44 = 51.24 \text{ N/m}$$

But $R_a = R_b$

And $R_a = (ql)\,{}^1\!/_2$ and $R_b = (ql)\,{}^1\!/_2$

$$R_a = \frac{51.24}{2} = 25.62$$

But 2.44 m $R_a = R_b$

Since the system is an UDL

$R_b$ = 25.62 N

To obtain bending moment "$BM$" for Equation (3) Hibler (2002)

$$BM = \frac{ql^2}{8} \quad (3)$$

$q$ = 21.0 N m$^{-1}$

$l$ = 2.44 m

$$BM = \frac{21.0 \times (2.44^2)}{8} = 15.63 \text{ Nm}$$

$BM$ = 15.6282 N m

From Equation (1)

$$\sigma_h = \frac{32BMd_0}{\pi(d_0^4 - d_1^4)}$$

$d_o$ = 33 mm = 0.033 m

$d_i$ = 24.5 mm = 0.00245 m

$\pi$ = 3.142

$$\sigma_b = \frac{32 \times 15.63 \times 0.0330}{3.142(0.330^4 - 0.0245^4)} = 6.362 \times 10^{-6} \text{ N/m}^2$$

Torsional control

$$\text{Angle of twist} = \frac{TXL}{GXT} \quad (4)$$

where, $T$ = Torque or torsional moment (N m); $L$ = Length of the shaft (m); $G$ = Modulus of rigidity of the shaft (N m$^{-2}$) (Khurmi and Gupta, 2004).

$$\text{Torsional moment, } T = \frac{2TXJ}{D} \quad (5)$$

$J$ = Polar moment of inertia of the cross section area about the axis of rotation (Nm$^{-2}$)

$$\text{But} \quad J = \frac{\pi(d_0^4 - d_i^4)}{32} \text{ (for Hollow shaft)} \quad (6)$$

$$T = \pi XJX \frac{(d_0^4 - d_i^4)}{\sigma XD} \quad (7)$$

where, $J$ = maximum shear stress (according to ASME code is 53 × 10$^6$ N m$^{-2}$); $\pi$ = 3.142; $D$ = Diameter of the shaft (m); $d_o$ = outside diameter of the shaft (m); $d_i$ = inside diameter of the shaft (m) (Khurmi and Gupta, 2004).

$$T = \frac{3.142 \times 53 \times 10^6 \times (0.0344^4 - 0.0245^4)}{16 \times 0.085} = 1010.9353 \text{ Nm}$$

$T$ = 1010.9353 N m

Diameter control $$dL = \frac{3\sqrt{32Tt}}{\pi t} \quad (8)$$

where, $BM$ = bending moment = 15.6282 N m; $T$ = torsional moment = 1010.9353 N m; $J$ = allowance shear = $53\times10^6$ (N m$^{-2}$); $T_t = \sqrt{(15.6282)^2 + (1010.9353)^2}$ = 1011.0561 N m$^{-2}$.

$$dL = \frac{3\sqrt{32\times1011.056092}}{3.142\times53\times10^6}$$
$$= 5.79 \text{ cm}$$

$dL$ = 5.7912 cm

$dL$ = 5.7912,

$\pi$ = 3.142

$D$ = diameter of the auger (m)

$S$ = pitch of the auger = 31 mm = 0.031 m

Driving power of the motor "$P$"

$$P = Q\times g(Lv\cdot K_i \pm H)k \quad (9)$$

where, $Q$ = capacity of the auger (kg s$^{-1}$); $K_i$ = coefficient of friction for grains and chopped hags ($k_i$ ranges between 2.2-2.7); $K_i$ = overloading coefficient ($k$ = 1.05-1.2); $Lv$ = length of the conveyor = 2.44 m, $H$ = perpendicular height = 1.840 m; $g$ = acceleration due to gravity = 9.81 m s$^{-2}$ (Ruina and Pratap, 2010).

From Equation (9)

$$P = 0.8333\times9.81(2.44\times2.7+1.840)\times1.2 = 82.68 \text{ W}$$

Therefore for safety factor the driving power "$P$" is taken to be 90 watt.

## 2.7 Driving force of the conveyor

If the conveyor must function, the angular moment is expected to be directly proportional to the angular force which should be greater than the required driving force.

Actual angular force $$F_w = \frac{2M_w}{d_i \tan(a+B)} \quad (10)$$

where, $M_w$ = Angular moment; $d_i$ = Diameter of screw where the bulk of the materials moves (m); $Q$ = Pitch angle, $R$ = 23°; $B$ = Frictional angle for the whole screw (°) (Ruina and Pratap, 2010).

From $$F = \tan B \quad (11)$$

$F$ = Coefficient of friction ($F$ = 0.32-0.58)

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

Therefore

$B = \tan^{-1} 0.38 = 20.81°$

Angular momentum for the shaft was calculated using the Equation (13)

$$M_w = \frac{q_m}{2\pi n}(\text{Nm}) \quad (13)$$

where, $q_m$ = weight of the materials to be transported (kg m$^{-1}$) and is given as Equation (14)

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

$n$ = number of screw rotation and is taken according to the conveyor materials for dense (Coarse) material.

where, $n$ = 0.8-1.5.

$V$ = Velocity of the auger (m s$^{-1}$) and is given as Equation (15)

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

where, $S$ = Pitch of the auger = 0.031 m s$^{-1}$; $V$ = 0.031 × 3.142 = 0.09740 m s$^{-1}$

From Equation (14)

$$q_m = \frac{0.8333}{0.09740} = 8.56 \text{ kg/m}$$

Therefore

Actual $q_m$ = 8.56 × 2.44 = 20.88 kg

From Equation (13)

$$M_w = \frac{20.88}{2\times3.142\times1.5} = 2.2151 \text{ Nm}$$

$$F_w = \frac{2\times2.2151}{110\tan(23^0+20.81^0)} = 0.04198 \text{ N}$$

Magnitude of the driving force "$F_0$" was determined using the Equation (16)

$$F_0' = q_m(L_v \pm H)f\cdot g(N) \quad (16)$$

where, $L_v$ = length of the conveyor (m); $H$ = vertical height (m); $f$ = coefficient of friction; $g$ = acceleration due to gravity (m s$^{-2}$).

therefore

$$F_0' = 8.56(2.44+1.84)0.38\times9.81 = 136.57 \text{ N}$$

The driving force $F'_0$ must be greater than the Angular force. i. e. $F'_0 > F_0$

i.e. 136.57 > 0.04198

## 2.8 Cylindrical housing

The volume of a cylinder $V=\pi r^2 h$ (17)

where, $r$ = radius of the cylinder = 63.5 mm; $h$ = height of the cylinder = 2440 mm.

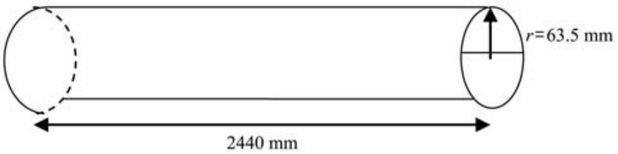
therefore

$$V = 3.142\times(63.5)^2\times2440$$

volume $= 3091316.98 \text{ mm}^3$

$= 0.0391 \text{ m}^3$

$V = 0.0391\ m^3$




The actual volume of the hopper is

$$V_r = V_1 - V_2$$

where, $V_1$ = Total volume; $V_2$ = Volume of the smaller frustum,

$$V_T = 40272606.67 - 4361500$$
$$= 39836456.67\ mm^3$$
$$= 0.398\ m^3$$

The efficiency ($\xi$) of the system was defined by the Equation (18)

$$\xi = \frac{\text{Total weight of grain}}{\text{Totalweight ofgrain fed into the hopper}} \quad (18)$$

### 2.9 Testing procedure

The conveyor was tested at no-load, after which between 1-3 kg each of some granular materials (Maize, Sorghum and Gari) were then introduced and replicated into the auger at different times through the hopper while the machine was running; the average quantity discharged at the outlet were collected and recorded as presented in Tables 1 through 3.

## 3 Results

Simple computation was used to obtain the average period of conveyance (s) of grain and average output capacity (kg $h^{-1}$). The values were tabulated in Tables 4 to Table 6.

**Table 1 Grain output at 45° angle of elevation for maize**

| Replication | Input, kg | Grain output, kg | Time taken to discharge, s |
|---|---|---|---|
| I | 1.00 | 0.99 | 22 |
| II | 1.50 | 1.45 | 25 |
| III | 2.00 | 2.00 | 25 |
| IV | 2.50 | 2.50 | 28 |
| V | 3.00 | 3.00 | 32 |

Note: Average output capacity (kg $h^{-1}$) = 263.05 kg $h^{-1}$.

**Table 2 Grain output at 30° angle of elevation for maize**

| Replication | Input, kg | Grain output, kg | Time taken to discharge, s |
|---|---|---|---|
| I | 1.00 | 1.00 | 20 |
| II | 1.50 | 1.50 | 21 |
| III | 2.00 | 2.00 | 24 |
| IV | 2.50 | 2.50 | 29 |
| V | 3.00 | 3.00 | 33 |

Note: Average output capacity (kg $h^{-1}$) = 263.05 kg $h^{-1}$.

**Table 3 Grain output at 0° angle of elevation for maize (horizontal position)**

| Replication | Input, kg | Grain output, kg | Time taken to discharge, s |
|---|---|---|---|
| I | 1.00 | 0.99 | 12 |
| II | 1.50 | 1.49 | 14 |
| III | 2.00 | 1.99 | 16 |
| IV | 2.50 | 2.49 | 18 |
| V | 3.00 | 2.99 | 24 |

Note: Average output capacity (kg $h^{-1}$) = 263.05 kg $h^{-1}$.

**Table 4 Output capacity, angle of inclination and period of discharge for maize**

| Angle of inclination, (°) | Output capacity, kg $h^{-1}$ | Average time taken to discharge, s |
|---|---|---|
| 0 | 407.046 | 17.6 |
| 15 | 313.04 | 20.6 |
| 30 | 282.353 | 25.5 |
| 45 | 263.05 | 26.6 |
| 60 | 216.33 | 31.25 |

**Table 5 Output capacity, angle of inclination and period of discharge for sorghum**

| Angle of inclination, (°) | Output capacity, kg $h^{-1}$ | Average time taken to discharge, s |
|---|---|---|
| 0 | 450.2 | 16.6 |
| 15 | 400.1 | 19.6 |
| 30 | 350.5 | 24.4 |
| 45 | 263.0 | 25.6 |
| 60 | 240.15 | 29.25 |

**Table 6 Output capacity, angle of inclination and period of discharge for gari**

| Angle of inclination, (°) | Output capacity, kg $h^{-1}$ | Average time taken to discharge, s |
|---|---|---|
| 0 | 460 | 15.6 |
| 15 | 410.2 | 17.6 |
| 30 | 365.3 | 21.4 |
| 45 | 310 | 22.6 |
| 60 | 300 | 24.5 |

## 4 Observation and discussion

Results from the test carried out revealed that some damages were experienced with maize due to the clearance between the auger and the housing barrel. These damages resulted from the shape and size of maize, found larger than the clearance between the auger and the housing barrel. However, grains of smaller shapes and sizes (Sorghum and Garri) were accommodated without damage. It was as well observed that when the conveyor was at horizontal position (i.e. $0^o$), the discharge was higher for all the grains tested. A decrease in discharge was discovered when the angle of inclination increases, hence, the discharge time increases simultaneously. The relatively shorter time required by the conveyor to transport grain at horizontal position was as a result of the less conveyance torque at horizontal level than at an elevated position i.e. gravitational force was one of the factors responsible for such. It was observed that as the angle of inclination increases, the output capacity reduces while the period of conveyance increases. This can be accounted for in the hypothesis that it requires minimum effort to move products in a horizontal manner than in elevated levels. These claims are in agreement with the studies of Hellewang (1985) and Schulze et al. (1997).

The efficiency of the machine was calculated using Equation (18) above.

$$Efficiency\ (\xi) = 100 - \left(\frac{0.05}{10}\right) = 99.95\%$$

At 99.5% efficiency, results from the study also indicated that the grain conveyor can be of tremendous usage to feed millers.

## 5 Conclusion

The conveyor was primarily developed and fabricated to eradicate drudgery involved in the indigenous method of handling grains especially into silos, bin, cribs, trailers and feed mills. Result obtained from the tests showed that the conveyor was effective to transport granular materials through an elevated location with an efficiency of 99.95%. The average output capacities were 407.05, 282.4 and 263.1 kg $h^{-1}$ for maize, 450.2, 350.5, 263.0 kg $h^{-1}$ for sorghum and 460.0, 365.3, 310.0 kg $h^{-1}$ for gari at corresponding angles of inclination of 0°, 30° and 45° respectively. Hence, with appropriate design consideration and adequate material selection to specification, the difficulties in manual loading of grains into storages, bin, silos, and processing points shall be overcome and an eventual prevention of wastage and damages will be achieved. This will also minimize the high cost of labour incurred in manual loadings.

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