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Development and Performance Evaluation of a Hand-Pushed Tiger Nut Harvester

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Abstract: Harvesting is one of the major problems encountered by tiger nut farmers in Nigeria. Manual harvesting system is the most commonly used method. This process is costly, labour intensive and time-consuming. The process does not also give farmers adequate returns to enable them to break even due to huge losses encountered. The objective of this study was to design, construct and evaluate a hand-pushed harvester that would eliminate the challenges being faced by small and medium tiger nut farmers during harvesting. Materials selection for constructing the harvester were based on their durability and availability, affordability and ease of replacement if damaged. They include mild steel (3 mm, 5 mm), 30 mm galvanized steel hollow pipe, 10 mm diameter steel rod, and 400 mm steel tyre. The developed harvester was evaluated at the experimental farm of the Institute for Agricultural Research (IAR). Results of the study show that the average field capacity ranges from 0.28 – 0.33 ha/h while the average field efficiency was between 77.78 – 80.49% depending on operating speed, moisture content and other properties of the soil. No field damage was recorded when the harvester was used as against an approximate 10.50% damage recorded in the manual harvesting method.

Keywords: Harvester, tiger nut, field capacity, field efficiency, field loss

I. Introduction

Tiger nut (*Cyperus esculentus* L.) is a grass-like shrub that belongs to the sedge family. It is cultivated in Africa, United States and other temperate zones of Europe and Asia [1, 2]. The yellow (larger size and attractive colour, usually consumed directly) and brown (tiny and hard that requires processing before consumption) varieties are the most common varieties planted in Nigeria, Niger and other Sub-Saharan African producing states. Tiger nuts plant is most frequently found in swamplands, edges of streams and ponds cultivated on a small and medium scale by rural farmers in Niger and some northern states of Nigeria [3]. It is locally called *aya*; *aki-hausa* and *ofio* in different parts of Nigeria. Tiger nuts have small tubers that are edible, sweet, nutty, flavoured tubers that contain protein, carbohydrate, sugars, vitamins and lots of oil and fibre [4, 5]. Its many uses include: beverage, milk and fermented milk product, flour, edible oil, honey, jam, beer, liqueur, chocolate, candies, soap, and as feed source [6, 7]. The nuts are also used in producing local non-alcoholic drinks that are traditional to West Africa (*Kunnun Aya*). They are also consumed as a snack food and their flour is used in baking [8]. In Nigeria, tiger nut is available in fresh, semi-dried and dried form in the markets where it is sold locally and consumed even uncooked. Because of its nutritional content and sole beneficial properties, tiger nut is believed to contain all the functional compounds needed for a balanced diet [9].

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Harvesting is a major post-harvest operation for the processing and storage of agricultural products. The traditional method of tiger nut harvesting is usually by manual means where the vines are uprooted with hand or hand tools with the entire root system. This system is labour intensive and time-consuming that is accompanied by severe field loss [10]. Manual harvesting system also caused depletion of soil fertility due to removal of the complete root system along with nitrogenous nodules. Harvesting of tiger nut is, therefore, one of the areas of its production and processing that need to be addressed due to the drudgery and wastages involved in order to improve timeliness as well as increase productivity and income of the farmer. The objectives of this study were, therefore, to design, construct and evaluate the performance of a hand-pushed tiger nut harvester (digger) in order to reduce the cost of manual harvesting, the drudgery involved as well as prefer possible solutions for reducing field losses while harvesting the crop.

II. Materials and Methods

A. Material selection

Materials used for constructing the harvester are; 3 mm and 5 mm mild steel, 30 mm circular (hollow) pipes, 10 mm diameter steel rod, 10 mm bearings, 10 mm square rod, 17 mm bolt and nuts and 400 mm diameter iron wheel. The bases for the choice of these materials were their durability and availability, ease of replacement if damaged and light in weight for safety and ease of transportation. Their cost is also affordable to a local fabricator and medium scale farmers. In its construction, the harvester was made in such a way that it is easy to operate and maintain while the components could easily be dismantled for replacement and repairs. Traction on the wheels has also been considered for proper movement in different soil conditions. Other materials used were a weighing scale, oven, soil sampler, soil adhesion and tri-axial soil test apparatus, measuring tape, steel rule and a digital stopwatch.

The components of the harvester consist of a frame, handle, iron wheel, harvesting doves and spikes as shown in Figure 1.

The frame is the skeletal/structural component on which all the components of the harvester were built, supported and attached. It was made from a 3 mm mild steel rod. All the components mounted on it were attached with bolts and nuts for ease of transport and replacement of defective parts. The harvester is equipped with a 400 mm diameter ripple-edge wheel. Its design was chosen in order to have a good grip of the soil to minimize slippage and getting stucked into the soil considering the fact that the soil is already loose. It is circular in shape with the centre bored to accommodate the shaft thereby enabling the wheel to rotate freely with the aid of a roller bearing when pushed. The handle was constructed using a 30 mm diameter circular galvanized steel hollow pipe. Ergornomic and anthropometric aspects were considered in such a way that suits a variety of users. It was attached to the frame to control and direct the harvester on the field. The spikes were made from 10 mm diameter steel rods which were flattened at their tips and supported at the top by a mild steel metal sheet. It was meant to work on a stony and rooted soils. The spikes did the actual harvesting by uprooting the nuts from the soil and inverts them on the soil surface, Figure 2. The furrow slicer was made from a 3 mm mild steel metal to form a typical sweep furrow of 18 × 18 mm. It is a dove-like structure that also does the harvesting operation of the tiger nut where the field is too weedy. It thus serves as an alternative tiger nut harvesting tool to the spikes.

The harvesting mechanism consists of three spikes mounted on a common bottom that is attached to the frame (Figure 2). It has an iron wheel that is supported by a main frame to ensure smooth movement of the harvester in the field. The spikes serves as the cutting edge that performs the actual harvesting operation. Provision was made for adjusting the spikes to penetrate at a depth below the tiger tuber zones

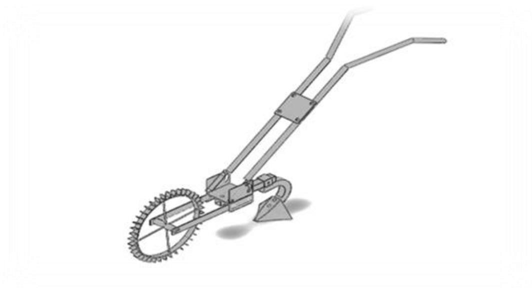

Figure 1: Pictorial View of the Developed Harvester

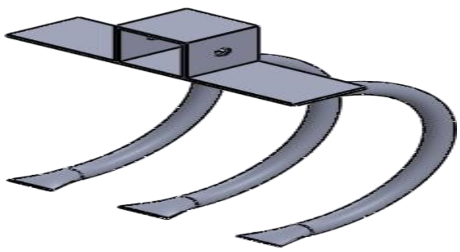

Figure 2: Pictorial View of the Harvester Spikes

such that field loss could be minimized. The forward movement of the harvester pulverize, pull out and inverts the already uprooted tiger nut plant from the ground. The nuts are then collected and cleaned in order to remove sand, stones and other contaminants such that their market value could be raised. Tiger nuts are usually sun-dried for up to three months depending on its moisture content and the prevailing environmental conditions before stripping and threshing. When the field is weedy, the spikes could be replaced with the dove-like furrow slicer (Figure 1).

B. Method

i. Machine Fabrication and Experimental Site

The tiger nut harvester was fabricated in the workshop of the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria between March and August 2019 with specifications as shown in Table 1. It was tested at the experimental farm of the Institute for Agricultural Research (IAR) Ahmadu Bello University, Zaria during the 2019 and 2020 harvesting season of the crop.

ii. Determination of Soil Properties

Soil samples were taken with the aid of the soil sampler ($\emptyset\, 0.38\, mm$) from two different locations of the experimental site. at a depth of 30 cm. Soil properties determined at the Soil Science Laboratory of the university include the moisture content and bulk density. Other properties determined are soil cohesion, internal angle of friction and soil adhesion pressure as shown in Table 2.

Table 1: Specification of the Harvester

Parameter	Specification
Weight	48 kg
Width	45 cm
Length	174 cm
Effective width	7.5 cm
Depth of cut	3.5 cm
Front height	40 cm
Rear height	75 cm
Number of spikes	3
Spike length	20 cm
Spike base width	20 cm
Spike angle	45°
Wheel diameter	40 m

Table 2: Soil Physical and Mechanical Properties

Properties	First location	Second location
Moisture (%) in db.	19.3	19.1
Bulk density (g/cm³)	1.30	1.28
Internal angle of friction (deg.)	32	30
Cohesion (k Pa)	4.6	4.2
Steel adhesion (k Pa)	1.13	1.11

iii. Field Evaluation of the Harvester

The field evaluation of the harvester was performed on a plot grown with tiger nut. The study area is a sandy-loam plot whose size was 100 m x 4.5 m. The parameters were determined:

The period within which the study was performed on the marked site was taken with the aid of a digital stopwatch.

The harvesting speed was calculated as follow [11]:

$$S = \frac{D}{t} \times C \qquad (1)$$

where:
S = harvesting speed, km / h.
D = length of the plot, m.
t = harvesting period, s.
C = conversion factor, [3.6].

The theoretical field capacity of the harvester was determined as suggested by [11]:

$$TFC = \frac{S \times W}{C} \qquad (2)$$

where:
TFC = theoretical field capacity of the developed harvester, ha/h.
W = width of the plot, m.
C = conversion factor, [10].

The effective field capacity of the harvester was determined as suggested by [11]:

$$EFC = \frac{A}{T} \times C \qquad (3)$$

where:
EFC = effective field capacity of the harvester, ha/h.
A = area marked for the study, m².
T = harvesting period, sec.
C = conversion factor, [0.36].

The efficiency of the harvester was determined from the following equation [11]:

$$FE = \frac{EFC}{TFC} \times 100 \qquad (4)$$

The per cent field loss of the tiger nuts that were exposed on the surface of the ground is given by the ratio of detached and left exposed tuber on the surface of the ground to the nuts collected in the sampled area. It was determined with the following expression:

$$T_e = \frac{T_s}{T_t} \qquad (5)$$

where:
T_e = Exposed Tuber Loss
T_s = Amount of Detached Tubers Lying Exposed on the Surface
T_t = Total Amount of Tubers Collected from the Plant in the Sampled Area

The per cent field loss of the tiger nuts that were unexposed on the surface of the ground is given by the following expression:

$$T_{ue} = \frac{T_r}{T_t} \qquad (6)$$

where:
T_{ue} = Unexposed Tuber Loss
T_r = Amount of Detached Tubers Remained inside the Soil in the Sampled Area

The total per cent field loss of the tiger nuts is the ratio of the sum of the exposed and unexposed nuts to the the surface of the ground given by the total nuts collected in the sampled area.

III. Results and Discussion

Timeliness of operation is vital in tiger nut harvesting in order to maintain a high-value produce during harvest. The time used to conduct the study in the fieldwork was observed and recorded (Table 3) while harvesting speed, theoretical and effective capacities, and efficiency of the harvester were shown in Table 4. The actual period within which the harvesting was performed and the total period the study took place was given in Table 3. Results obtained show that the actual period of harvesting and the total period of the exercise in the second location were lower than those obtained in the first location. This may be attributed to the fact that soil properties determined in the first location were characterized by higher moisture level and bulk density, cohesion and adhesion force as compared to the soil in the second location (Table 2). It would be expected that the harvesting time in the first location would be higher than in the second location. Moisture content was found to have an adverse effect on harvesting operation. A similar trend was earlier reported on the performance evaluation of a guided horizontal conveyor rice harvester [12].

Table 3: Field Time Recorded

Location	Time Taken (h)		
	Effective time	Turning time	Total Time
First location	0.033	0.012	0.045
Second location	0.028	0.011	0.039

*Each value is an average of three replicates.

Table 4: Field Speed, Capacities and Efficiency

Location	Speed (km/h)	Theoretical capacity ha / h	Effective capacity ha / h	Field efficiency %
First location	0.80	0.36	0.28	77.78
Second location	0.92	0.41	0.33	80.49

*Each value is an average of three replicates

Harvester field speed (Table 4) in the second location was higher than what was obtained in the first location by 0.12 km/h. Logically, soils with lighter moisture contents would be lighter as such operating speeds on such soils would be faster than heavier soils having more moisture content. However, lower speed in the first location may be due to its higher resistance force as a result of its higher shear strength that could increase wheel slippage as compared to the lighter soil in the second location. Results of this study, therefore, shows that speed is affected by soil properties that include moisture content, bulk density and soil hardness. The study thus observed that average field capacity increases with an increase in speed, a similar trend that was also reported [13,14]. The result obtained was also supported by the findings that soils with higher moisture levels, bulk density, cohesion and adhesion force were observed to have less operating speeds thereby having more field time [15, 16].

However, the theoretical field capacity, effective field capacity and the total field efficiencies observed in this study were lower in soil sample in the first location than soils with lighter moisture levels, bulk density, cohesion and adhesion force as was observed in Tables 3 and 4. These results were also in agreement with the findings in a performance evaluation of a groundnut harvester earlier developed [17]. Results obtained also agreed with the earlier assertion that higher speed reduces the total field time thereby increasing the theoretical field capacity but reducing the effective field capacity [18]. Higher speed also translates to an increase in the field efficiency of the harvester. Moisture content and other soil properties were thus found to be major influencing factors in determining the harvesting capacities and efficiencies of the harvester as reported [19].

The study conducted also tried to investigate field losses during tiger nut harvesting. Such losses were classified as losses where the lost tubers were exposed on the ground surface and those that were not exposed but buried in the soil. Results obtained and presented in Table 5 shows that the average exposed tuber loss in the first and second locations were 1.00 % and 1.50%, respectively. However, there was no field loss recorded for the unexposed tuber loss in the first location while 0.50% loss was recorded in the second location. This result signifies good and adequate soil penetration by the harvester since the rate of unexposed field losses were insignificant. No tuber damage was also observed in both locations.

The average field losses of the harvester and the manual method of harvesting tiger nuts have also been compared. The percentage losses of the developed harvester were relatively decimal when compared with manual harvesting that is the common method of harvesting by tiger nut farmers in Northern Nigeria (Table 6).

Table 5: The Average Tubers Losses

Location	Field Losses (%)		
	Exposed Tuber Loss	Unexposed Tuber Loss	Damaged Tuber
First location	1.00	0.00	0.00
Second location	1.50	0.50	0.00

*Each value is an average of three replicates.

Table 6: Comparison of Field Loss in Mechanical and Manual Harvesting Methods

Harvesting Method	Field Losses (%)		
	Exposed Tuber Loss	Unexposed Tuber Loss	Damaged Tuber
Developed Harvester	1.00	0.00	0.00
Manual Method	6.80	8.50	10.50

*Each value is an average of three replicates

Results obtained show that only 1% of the nuts were lost and exposed on the field when the developed harvester was used as compared to 6.80% when the manual method (using hoe) was used. There was no unexposed field loss recorded when the developed harvester was used as against the value of 8.50% obtained in the manual harvesting system. Similarly, no pod damage was observed in mechanical harvesting while 10.50% of the pods were damaged in manual harvesting. Higher pod damage was recorded in the manual system probably because tuber depth was not taken into account by the farmer. Results obtained, therefore, revealed mechanical harvesting has more advantage than manual harvesting as it reduces field loss, costs of harvesting and timeliness of operation.

Field losses in the manual tiger nut harvesting method may occur when the plants are being dug from the soil and shaken to remove dirt then placing nuts on windrows for drying. The study was in conformity with the observations that farmer's inability to reach the depth of the tiger nut roots was the main caused of high field loss [20]. The results obtained also shows that lower moisture content of soil results in a decrease in harvesting efficiency and could be another reason for the increased field losses for both methods of tiger nut harvesting. It was thus clear from the obtained results that the moisture level of the soil greatly influenced harvesting efficiency. Weakened pegs due to moisture loss on the plant as a result of reaching maturity stage also result in field loss.

The study revealed that soil moisture level and soil resistance inversely relate to each other. Decrease in soil moisture level results in an increase in soil strength thereby causing the pegs to dry and results in an increase in field losses and a reduction of harvesting efficiency. It was also noted that excessive field loss resulting from a heavy digging process is unavoidable when the soil is dry [20]. A delay in harvesting after physical maturity of the nut could also result in severe field loss. A similar case was also confirmed by other researchers [21]. It is thus possible to reduce field loss when the crop is harvested at suitable soil moisture content and other environmental conditions.

IV. Conclusion

The hand-pushed Tiger nut harvester was developed and tested in the experimental farm of the Institute for Agricultural Research (IAR) Ahmadu Bello University, Zaria. The study revealed that drudgery involved in tiger nut harvesting was reduced while field efficiency of the harvester is higher when the moisture content of the soil is less. The study also revealed that soil moisture content and other properties of the soil are important factors that have significant effects on tuber loss as delay of harvesting increases tuber loss due to decrease in soil moisture and weakened pegs then when the nut must be harvested in the optimal time. The harvester was designed and constructed with locally available materials and was estimated to cost about ₦18, 000:00. The results of the study have demonstrated that the harvester is effective, reduce drudgery and cost of operation and timeliness in operation.

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References

[1] Tetteh, J.P. and Ofori, E. "A Baseline Survey of Tiger Nut (*Cyperus esculentus*) Production in the Kwahu South District of Ghana", *Ghana Journal of Agricultural Science,* vol. 31, 1998, pp. 211-216.

[2] Bamishaiye, E.I. and Bamishaiye, O.M. "Tiger Nut: As a Plant, its Derivatives and Benefits", *African Journal of Food, Agriculture, Nutrition and Development*, vol. 11, 2011, pp. 5157-5170.

[3] Oladele, K.A., Osundahunsi, F.O. and Adebowale, A.Y. "Influence of Processing Techniques on the Nutrients and anti-nutrients of Tigernut (*Cyperus esculentus* L.)", *World Journal of Dairy & Food Sci.ence,* vol. 2, 2009, pp. 88-93.

[4] FAO. Traditional Food Plants: Food and Nutrition Paper 42 Rome, 1988, pp. 239-242.

[5] Belewu, M.A. and Abodunrin, O.A. "Preparation of Kunnu from Unexploited Rich Food Source: Tiger Nut (*Cyperus esculentus*)", *Pakistan Journal Nutrition*, vol. 7, 2008, pp. 109-111.

[6] Asante, F.A., Oduro, I., Ellis, W.O. and Saalia, F.K. "Effect of Planting Period and Site on the Chemical Composition and Milk Acceptability of Tigernut (Cyperus Esculentus L) Tubers in Ghana", *American Journal of Food and Nutrition*, vol. 2, no. 3, 2014, pp. 49-54.

[7] Muhammad, N., Bamishaiye, E., Bamishaiye, O., Usman, L., Salawu, M.O., Nafiu, M.O. and Oloyede, O. "Physicochemical Properties and Fatty Acid Composition of Cyperus Esculentus (Tiger Nut) Tuber Oil*", Biores. Bull.* vol. 5, 2011; pp. 51-54.

[8] Codina-Torella, I., Guamis, B. and Trujillo, A.J. "Characterization and Comparison of Tiger Nuts from Different Geographical Originphysico-Chemical Characteristics and Protein Fractionation*", Indian Crop Production journal,* vol. 65, 2015, pp. 406-414.

[9] Chukwuma, E.R., Obioma, N. and Christopher, O.I. "The Phytochemical Composition and some Biochemical Effects of Nigerian Tiger Nut (Cyperus esculentus L.) tuber", *Pakistan Journal of Nutrition*. vol. 9, no. 7, 2010; pp. 709-715.

[10] Olukunle, O.J. "Developments in Grain Harvesting Mechanization", *Journal of Agricultural Engineering and Technology (JAET)*, vol. 18, no. 1, 2010, pp. 12 – 19.

[11] Kepner, R.A., Bainer, R. and Barger, E.L. "Principles of Farm Machinery", (*3 edition), Avi Publishing Company Inc. Westport, Connecticut*, USA., 1978.

[12] Ogunlowo, Q.O. and Olaoye, J.O. "Development and Performance Evaluation of a Guided Horizontal Conveyor Rice Harvester", *Agrosearch Journal,* vol. 17, no. 1, 2017, pp. 66– 88.

[13] Moheb, M.A. "Construction and Manufacture a Self-propelled Machine Suits for cutting some Grain Crops to minimize Losses and maximize Efficiency", *Misr. Journal of Agricultural engineering***,** vol. 23, no. 3, 2006, pp. 509 – 531.

[14] Guruswamy, T., Desao, S.R., Veeranagouda, M. and Barker, R.D. "Performance Evaluation of a Vertical Conveyor Reaper Windrower", *Kamataka Journal of Agricultural Science***,** vol. 9, no. 1, 1996, pp. 102-105.

[15] Nkakini, S.O. "Draught Force Requirements of Disc Plough at Various Tractor Forward Speeds in Loamy Sand Soil, During Ploughing", *International Jounal of Advanced Research in Engineering and Technology* , vol. 6, 2015, pp. 52-68.

[16] Naderloo, L., Alimadani, R., Akram, A., Javadikia, P. and Zeinali, H.K.. "Tillage Depth and Forward Speed Effects on Draft of Three Primary Tillage Implements in Clay Soil", *Food, Agriculture*

and Environment , vol. 7, no. 3&4, 2014, pp. 382-385.

[17] Zaied, M.B., El Naim, A.M., Dahab, M.H. and Mahgoub, A.S. "Development of Powered Groundnut Harvester for Small and Medium Holdings in North Kordofan State in Western Sudan", *World Journal of Agricultural Research,* vol. 2, no. 3, 2014, pp. 119-123.

[18] Ibrahim, M.M., Amin, E. and Farag, A. "Developing a Multi-Purpose Digger for Harvesting Root Crops", *Misr J. Ag. Eng.,* vol. 25, no. 4, 2008, pp. 1225-1239.

[19] Ademilyi, Y.S., James, D., Ozumba, I.C and Olowonibi, M.M. "Performance Evaluation of a Tractor Drawn Groundnut Digger/Shaker", *NCAM Research Publication*, 2004, pp. 115 - 122.

[20] Roberson, G.T., Jordan, D., Lassiter, B. and Wilkerson, G. "North Carolina State University. Departments of Biological and Agricultural Engineering, and Crop Science", 2010.

[21] Singh, F. and Oswalt, D.L. "Groundnut Production Practices Skill Development Series", no. 3, 1995.

Appendix

Table A1: Bill of Engineering and Material Evaluation

S/N	Description	Quantity	Rate (₦)	Amount (₦)
1	3mm mild steel	Quarter length	-	3500
2	5mm flat bar	One length	-	3500
3	Bolt and nut	20 pieces	50	1000
4	10 mm iron road	0.75 of a length	2000	1500
5	Cutting disc	One disc	1000	1000
6	Electrode	Half pack	1000	500
7	10 mm Bearing	Two	250	500
8	30 mm Round pipe	One length	2000	2000
10	Square road	Quarter length	2000	500
11	Paint	⅓ gallon		500
12	Transportation	-		500
13	Miscellaneous			3000
14	**Total**			**18000**

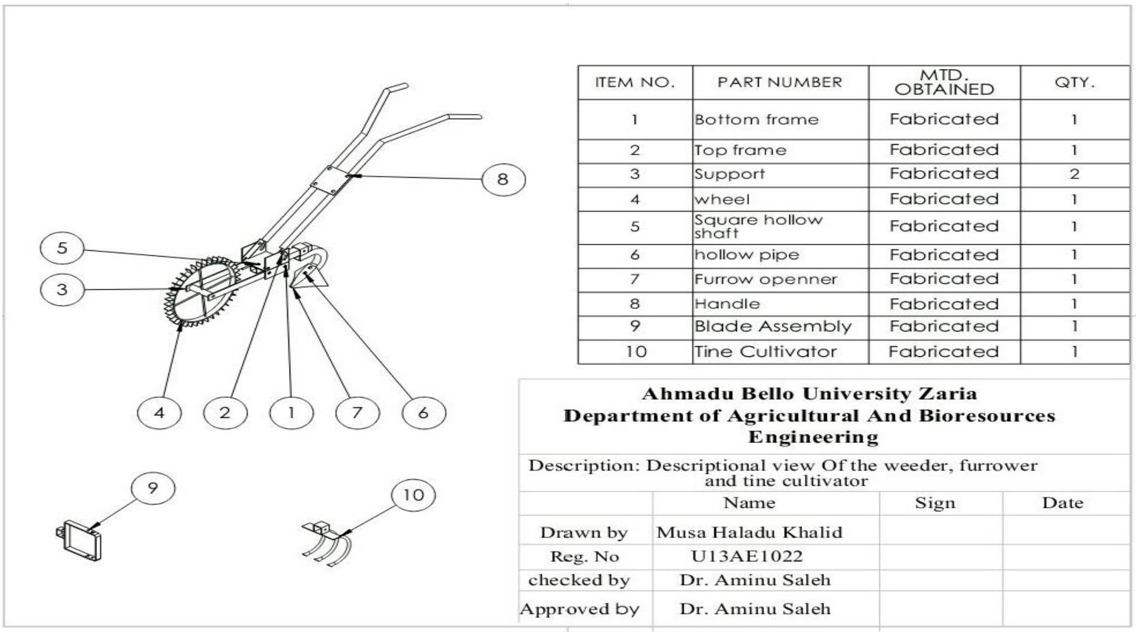

Figure A1: Orthographic view of the Tiger Nut Harvester