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EFFICIENCY ASSESSMENT OF A DEVELOPED MECHANICAL PALM FRUIT HARVESTER

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ABSTRACT

A notable factor responsible for decline in palm fruit production in Nigeria is in the area of harvesting; hence a need to develop a technology that can cut fruit bunches easily, fast, cheap and efficiently. This study developed and evaluated a Mechanical Palm Fruit Harvester (MPH) to ease palm fruit harvesting. The physical palm fruit parameters such as width of bunch and width of palm fronds needed to design and develop the machine were obtained. The machine was made up of a 2 Kw gasoline engine, 2 poles with a length of 3.04 mm each, shafts, hubs and a cutting disc of radius 170 mm. A maximum force of 224.6 N was required to cut off a matured frond. The developed machine was evaluated by total time to harvest, theoretical speed, throughput capacity, efficiency and cost of fabrication. The total time to harvest and the throughput capacity were 2.2 hrs/ha and 0.45 ha/hr respectively. It had a throughput capacity value of 65 FFB/h and a maximum efficiency of 75 %; this efficiency was attained. When used to harvest a palm fruit tree of 4 m high. Field tests of the MPH method suggest that it performed well in reducing the time to harvest. The cost of fabrication of the harvester was ₦ 22,350. MPH could be deployed to palm oil plantations due to its mobility and ease of operation. It could be a suitable replacement for existing crude methods of harvesting palm fruit.

Keywords: Development, MPH, Palm Fruit, Machine, Harvest

Introduction

Oil palm can be divided into two species which are *Elaeis oleifera* and *Elaeis guineensis.* There are three types of *Elaeis guineensis* which are *pisifera*, *dura* and *tenera*. *Pisifera* has a pollen type shell, meanwhile *dura* has a thicker shell and a lesser oil content compared to *tenera* which is a hybrid between *pisifera* and *dura*. Tenera has high oil content; therefore this type is suitable for planting material for commercialization purpose (Hai, 2002).

In his report (Adetan *et al.*, 2007), stated that palm oil productivity in Nigeria has declined steadily and one of the notable factors responsible for this decline is in the area of harvesting. Palm fruit harvesting operation requires 60% of total labor for the crop which constitutes about 50% of the total production cost (MuhamadJamil, 2008). Harvesting schedule will depend on the ripening of fruits as observed on plantations (Owolarafe and Arumughan, 2007). During early harvesting rounds, it is suggested to carefully cut off the fresh bunch without having to cut off any leaf, so as not to damage the fruits (Adetan *et al.*, 2007).

Some of the existing tools/methods of harvesting palm fruits are:

i. Cutlass or chisel method usually used to harvest plants less than 2.5 m tall.

ii. The bamboo pole and knife (BPK) method: this is used to harvest palm trees from moderately tall to 9 m in height (Adetan *et al.,* 2007)

iii. The Aluminum pole and knife (APK) method; this is similar to that of BPK

iv. Single rope and cutlass/axe (SRC) method; this is used to harvest very tall trees

Researchers have been attempting to solve palm fruit harvesting problems and also improve on existing harvesters; hence palm fruit harvesters have gone through different modifications (Aramide *et al.*, 2015). Factors taken into consideration when developing mechanical harvesters include; physical assessment, light weight, ability to harvest from both high and short palm trees, and the safety of the operator. Table 1 shows some physical parameters of the palm tree.

Table 1: Physical Parameters of Palm Fruits

Parameter	***Research study***	***Literature***
Height of palm tree	5-12 m	6 – 20 m
Width of bunch stalk	70-120 mm	70 -130 mm
Width of palm frond	75 -130 mm	70 – 130 mm
Bunch weight	15-25 kg	10 – 35 kg
Fruit color	Yellowish- red	Yellowish- red
Fruits per bunch	2200- 2800	1000 -3000

While the leaves prevent direct access to the bunches and with the stalks obscured, harvesting Fresh fruit bunch is a labor intensive occupation which presents significantly different ergonomics hazards over time as the trees grew taller corresponding to the age of trees (Yee *et al.,* 2013).High charges are always demanded by laborers for harvesting, the time taken for harvesting is very high when compared to other farm products, and manual harvesting is injury – prone due to thorns and sharp edges (Aramide *et al.*, 2015). According to (Yee *et al.*, 2015) ergonomics analysis shows that farmers adopt force and repetitive movement that increase operator workload resulting in lower back and upper limb pains.(Abdullah *et al.,* 2011) identified a series of risk factors such as handling heavy, awkward postures and poor safety standards with the use of crude method of palm fruit harvesting; these are responsible for 80% accidents on palm fruit farming.

These accidents have serious economic impact on palm fruit harvesting due to direct and indirect cost of harvest. Pain in the knee has been associated with bending, kneeling or stooping usually adopted particularly while climbing up and down using ladder for harvesting tasks (Cooper *et al.,*2014). In terms of self-reported musculoskeletal disorders, the prevalence of having pain in any part of the body among crude method harvesters were considerably high, compared to a general survey among workers in the oil palm plantation (Henry *et al.*, 2015).Report from (Jelani *et al*., 1999) also showed that existing harvesters performed low when evaluated. The parameters that critically evaluates the performance of a machine, and help to determine its acceptability include; theoretical speed, throughput capacity, effective field capacity, theoretical field capacity,

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performance efficiency and the cost of fabrication. This study aimed at solving the major challenge in palm fruit harvesting by adopting technological approach in developing a harvester that can be an improvement on the existing ones. The overall objective of the present work was to design, construct and evaluate the performance of a palm fruit harvester.

Materials and Methods

This study was carried out on a palm fruit farm located in Idi-Isin, Ibadan, Nigeria. The area lies between latitudes 7°26'N and 7°31'N;longitudes 3°36'E and 3°40'E,with an annual rainfall of about 1300mm-1500mm(Kareem *et al.*, 1999). The information for the physical parameters of a palm fruit bunch was assessed from both literature and physical measurements. The design for respective machine parts were calculated, the machine was fabricated based on the design; it was then tested on a palm fruit plantation in Ibadan and evaluated.

Design of Machine Parts

The component design for some of the machine parts are as follows;

i. Disc selection

The width of a palm stalk ranges between 70 mm – 130 mm for most matured tree; for this research work, 224.6 N was considered for the disc cutting force (force required for a claw to cut the most matured palm frond(Jelani*et al.*, 1999).

The following assumptions were made;$Force\ (F) = 224.6$

$Disc\ radius(r) = 130mm\ (stalk\ width) + 20\ mm\ (centre\ hub) + 20\ mm\ (allowance)$
$(I.e. Radius\ (r) = 130 + 20 + 20 = 170\ mm)$
Disc thickness (considering stainless steel) = 2 mm
$Mass\ of\ disc = density\ (\rho)\ x\ volume\ (\pi r^2 t)$ (1)
(Where → density of stainless steel (7870 kg/m^3), r →radius of the disc, t → thickness of disc)
$M = 7870\ x\ 3.142\ x\ 0.17870$ x 3.142 x 0.17 $x\ 0.002 = 1.43\ kg$
Thus; $Disc\ weight = 9.82\ x\ 1.43 = 14\ N$

To calculate the power required to generate a 224.6 N force by the disc

$P = T\omega$ (2)
But $T = F\ x\ r$ (Where F = cutting force) (3)
Therefore: $T = 224.6\ x\ 0.17 = 38.182\ Nm$8.182 Nm
Also; $F = m\omega^2 r$, therefore $\omega = \sqrt{F/mr}$ (4)

$$\omega = \sqrt{224.6/\ (1.43\ x\ 0.17)} = 32.36\ rad/s$$

Therefore,$P = 38.182\ x\ 32.36 = 1.2\ KW$

This suggests that a machine with a minimum power rating of 1.2 kW would be required, therefore, an engine of 2 kW power rating was considered to accommodate power loss.

ii. Shaft selection

Shaft diameter: (*ASME code was used in determining the diameter of the shaft*)

$d^3 = 16/sy\pi\sqrt{((\mathrm{MtKt})^2 + (\mathrm{MbKb})^2)}$ (5)

Shear yield strength (sy) (N/m^2) = 4.4 x 10^8 (for steel)
Mt = shaft torque (Nm)
Mb = applied bending moment (Nm)
Kb = shock fatigue factor (moments) = 1.5 Nm
Kt = shock fatigue factor (torque) =1.5 Nm (for rotating steel shaft with suddenly applied shock)

To determine the torque (Mt) on shaft;

$Torque\ on\ disc = Torque\ on\ gear = 38.182\ Nm$ = 38.182Nm
Since$\mathrm{T1/T2} = \mathrm{y/x}$ $(T1 = torque\ on\ gear, T2 = torque\ on\ pinion)$
T_2 = (T1 x X)/y (6)
$T2 = (38.182\ x\ 7)\ /\ 10 = 26.73\ Nm$= $(\ Mt)$

To determine the maximum bending moment;

$Rc\ (weight\ of\ disc) = 14N, RB\ (normal\ reaction\ due\ to\ weight\ of\ shaft)$

$\sum MA = 0\ , 14\ x\ 3.04 + 1.52RB = 0$3.04 + 1.52R = 0, $RB = -30.4/1.52 = -28N$

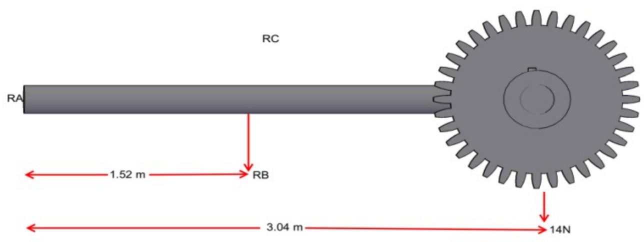

Figure 1: Free body diagram for shaft

Therefore to determine bending moment (MB), refer to Figures 2 and 3;

$\sum MB = 0, \quad MB = 14X, For\ X = 0, MB = 0 (For\ X = 1.52), \quad MB = 14\ x1.52 = 21.28\ Nm$

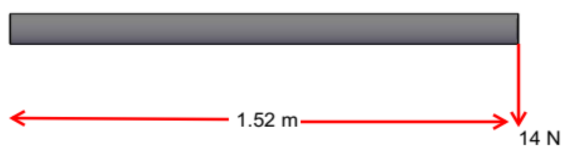

Figure 2: Diagram of a section of shaft

Consider section $1.52 \leq X \leq 3.04$

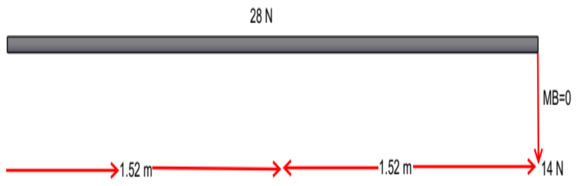

Figure 3: Diagram of a section of shaft

$$MB = 0$$

$MB = 14X - 28(X - 1.52)$,$(For\ x = 1.52,\ MB = 21.28\ Nm)$, M =21.28 Nm)

$$For\ X = 3.04m$$

$MB = 14\ x\ 3.04 - 28(1.52) = 0\ Nm$ [*Maximum bending moment is 21.28 Nm]*

Thus: $d^3 = 16 / \pi\ x\ 4.4\ x 10^8 \sqrt{(1607 + 1018.89)}$

$d = 0.0084\ m = 8.4\ mm$ [Therefore, a shaft with diameter 10 mm was selected].

iii. Pole selection

$$Young's\ modulus\ (E) = 700\ x\ 10^8\ N/m2\ (for\ aluminum\ materials).$$

$$Pole\ diameter\ (external) = 25.5\ mm$$

$Pole\ diameter\ (internal) = 22.5\ mm$ (This would allow the shaft rotate freely)

$Pole\ length\ (L) = 6000\ mm$ (This is to ensure that the shaft extends a little longer than the pole, this will allow the extra length of the shaft fit into the hubs)

Determination ofcritical load that could cause buckling on the pole;

For one end fixed and the other subjected to a compressive loading, Euler critical buckling formula is given as: $Critical\ load\ (Pcr) = \pi^2 EI / 4L^2$ (7)

But, i = $\pi d^4/64$ (8)

i= $1.92\ x\ 100^8$

Therefore: $Pcr = 3.14^2\ x\ 700\ x\ 10^8\ x\ 1.92\ x\ 10^{-8}/4\ x\ 6^2$

Pcr = 92N *(This is greater than the weight carried by the pole, hence there cannot be buckling)*

Machine parts assembly

The following are respective components of the fabricated machine.

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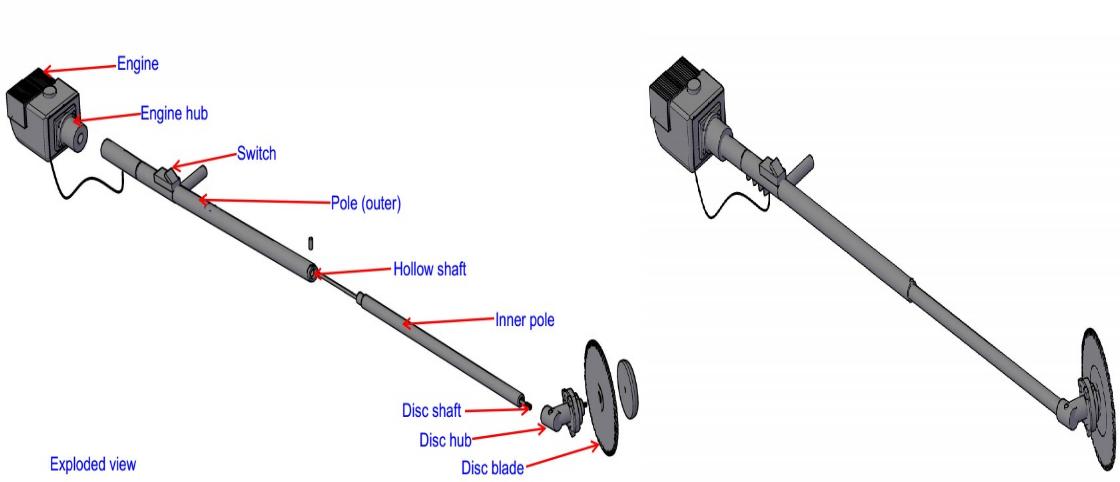

Figure 4: Exploded diagram of and assembled machine parts

Machine testing

The Mechanical Palm fruit Harvester (MPH) was tested on selected oil palm plantationsin Ibadan. The extension section of the MPH was always adjusted to suit respective palm tree height for effective harvesting.The palm tree heights harvested ranged from 4-12 m.The height of each palm tree, the time taken to harvest each bunch and the number of bunches harvested were all recorded.

Evaluation parameters

The following parameters were considered in evaluating the fabricated machine; theoretical speed, throughput capacity, efficiency of the machineand cost of fabrication.

i. **Theoretical speed (C_{th})**

C_{th} (ha/hr)= $(V \, x \, W)/10$ (9)

Where V … speed of machine (Km/hr), W … width of machine (m)

ii. **Throughput capacity (FFB/h):** Throughput is the rate of harvest;

$Throughput \; = FFB/t$ (FFB/h) (Onwualu*et al.*, 2006) (10)

FFB … number of fresh fruit bunch harvested, t … total time taken to harvest

iii. **Performance efficiency (E)**

E (%) $= (Cff/Cth)$ (Onwualu*et al.*, 2006) (11)

Cff … Effective field capacity (ha/hr), Cth … Theoretical field capacity (ha/hr)

iv. **Cost of fabrication ….** The cost incurred during the fabrication of the machine

Result and Discussion

The performance of MPH at different palm tree heights is as presented in Table 2.The

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harvest for each height was replicated five (5) times, A total of 35 bunches of palm fruits were harvested. It took 1955 seconds to harvest the 35 bunches; therefore it took an average of 55.85 seconds to harvest a bunch and 65 FFB/ hour. From equation (9), the theoretical speed of harvest calculated was 0.45 ha/hr, while it took 2.2hrs to harvest a hectare of palm fruit plantation.

Table 2: Test performance of MPH during harvest

	Number of bunches	Average height (m)	Total time(s)	Average time/FFB (s)
	5	4	250	50
	5	4	255	51
	5	6	265	53
	5	8	278	55.6
	5	8	280	56
	5	9	300	60
	5	10	327	65.4
Total	**35**	**49**	**1955**	**391**
Mean	**5**	**7**	**279.29**	**55.85**
S.D			**25.32**	

The performance efficiencies of the palm fruit harvester when used to harvest on palm tree heights of different heights are as presented in a graphical illustration in figure 5. Performance efficiency was calculated from equation (11). Highest efficiency of 75 % was recorded at a height of 4 m, while the lowest efficiency was recorded at a height of 10 m. The efficiency of the machine reduces as the height of the tree is increased. This result is in line with the report of (Aramide *et al.*, 2015), while the least efficiency was recorded at the highest height considered for this study.

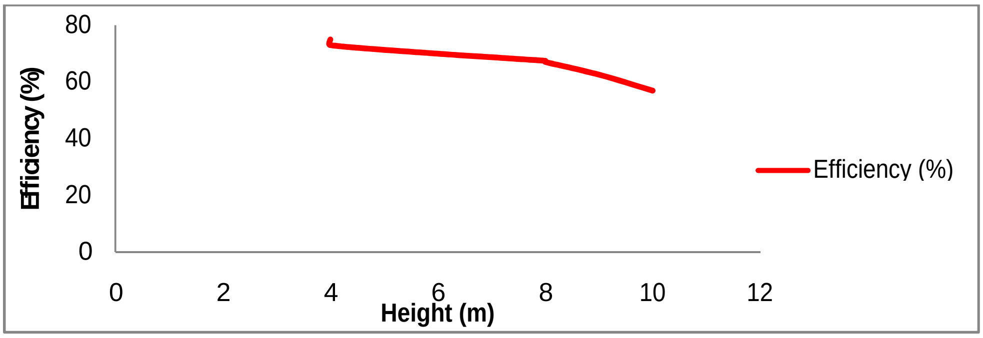

Figure 5: Efficiency curve of the developed machine (MPH)

Table 3 is the bill of Engineering; it is the cost incurred in the course of fabricating the machine. The cost of labor was not included because it was a research work and the charge would not be a true reflection of the work.

Table 3: Bill of Engineering

S/N	Material	`Quantity	Amount (₦)
1	2 kW gasoline engine	1	15, 000
2	Pole/Shafts	2/2	4,300
3	Hub	2	1,500
6	Bolt and Nut	12	300
7	Sheet metal	¼ sheet	1,250
	Total		**22, 350**

Conclusion and Recommendation

Field tests of the MPH method showed that the MPH method performed very well in reducing the time spent to harvest. The throughput value was 65 FFB/h. The time expended in climbing up and down in harvesting methods like in SRC was not necessary because MPH could easily be adjusted to suit the height of the respective palm fruit to be harvested. The developed machine had a maximum efficiency of 75 % and was obtained at a height of 4 m.MPH is considered easy to use when compared to other crude methods of harvesting. Its durability, mobility and operation distinguish it from others. Harvesting palm fruit using MPH also reduced drudgery, very little or no human skill is required to harvest. Therefore it is recommended that this machine be deployed into palm tree farming and used for harvesting palm fruits.

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