



DESIGN, FABRICATION, AND EVALUATION OF AN IMPROVED IMPLEMENT FOR HARVESTING INDIGENOUS TREE CROPS

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ABSTRACT :

Harvesting is the act of removing a crop from where it was growing and moving it to a more secure location for processing, consumption, or storage. Some root crops and fruit trees can be left in the field or orchard and harvested as needed, but most crops reach a period of maximum quality, that is, they ripen or mature and deteriorate if left exposed to harsh weather and vermin. The major factor determining the harvest time is the crop's maturity, and weather conditions. Picking, packing, storage, and transportation are important considerations in harvest operations. The design of the implement for harvesting tree crops involves cultural modifications. To that effect, consideration of Ibo norms became imperative. A locally made implement called "Nguru", used to harvest fruits like oranges and mangos, gets damaged during harvesting. This modified implement provides a solution to reducing the rate at which fruits are damaged during harvest operations. The indigenous fruit harvesting implement fabricated includes: citrus 1 and 2 harvesters are used on top and ground, respectively. Human–implement–weight ratios (W_{hir}) were found to be 10:7:5:1, respectively. This result proved the parametric pull and push force (F_p) on human implement–weight designs as 588.6 N (60 kg x 9.81) and 0.002 N, which confirmed the approved standard for higher human body weight and force required to pull off fruits from the stalk, respectively, thereby making it light enough to be used by man. These implements can be used to substitute the local "Nguru" used in Igbo for harvesting tree crops, at affordable prices.

Keywords: Human–Implement–Weight Ratio, Citrus Harvesters, Local Modification, Pulling and Pushing Force, Harvesting, Crop maturity, Storage, Transportation, Fruit damage,

INTRODUCTION

Some root crops and tree fruits can be left in the field or orchard and harvested as needed, but most crops reach a period of maximum quality, that is, they ripen or mature and deteriorate if exposed to worse conditions. (Baugher, 2009; UN Food and Agriculture, 2017). While Chinchuluun et al (2009) observed that the major factor determining the harvest time is the crop's maturity. Other factors, such as weather, availability of harvesting equipment, pickers, packing, storage, and transport facilities, are important considerations. Now, considering the availability of harvest equipment, there is also a need to look into the designs of implements suitable for harvesting these fruits and vegetables to avoid bruises and damage to the fruits and the trees. In the design of implements, the culture of the designer influences the implements being produced. (NASS, 2007).

Most of the equipment sent to us from Europe and America is based on their cultural methods of harvesting. Africans and Nigerians in particular need to consider culture in harvesting fruits and vegetables, indigenous to us. This calls for the need for us to start designing implements to harvest our indigenous fruits without bruising the fruit or harming the tree. These indigenous or tropical fruits include orange, guava, mangoes, avocado pear, and cocoa. (Abou EI-Kheir, 1993; Layne, 1996; Futch et al, 2004).

The first consideration in the design of any implement is to establish the functional requirements. This can be found in the cultural method of harvesting any crop in our country. For fruits in question like pawpaw, oranges, guava, and cocoa, there are tendencies for these fruits to fall and get bruised in the process. A simple method of collecting harvested fruit, like pawpaw, guava, orange, and mangoes, is to make a net for the collection while it is harvested right up the skyways.

The primary focus of the augmented fruit harvesting research effort is to identify and develop fruit harvesting solutions that enable growers to reduce their harvesting production cost as well as decrease the amount of fruit damaged during harvest. The largest contributing factor to harvesting operations is the cost of labor. Therefore, the design philosophy governing engineering decisions is to determine what designs have the greatest potential to minimize costs. (FAOSTAT, 2018).

The approach is to develop systems that enable current workers to simply harvest fruit more efficiently as compared to current practices, rather than focusing on replacing the laborer entirely, while considering ways of improving worker efficiency. Various agricultural and biological equipment has been constructed to create solutions that enabled a reduction in fruit damage during harvest- (Kepner et al, 1971; El-Khwaga, 1999; Abou-elmagd et al, 2002; Ojha and Michael, 2003; Burks et al, 2005; Sanders, 2005; Khurmi and Gupta, 2008; Wagner and Sauls, 2012; FAOSTAT, 2017 & 2018).

This project is focused on developing solutions that provide the largest benefit at the smallest possible capital investment, leading its way to the designing and fabrication of some indigenous fruit harvesting implements, thus increasing the market value of agricultural products, thereby meeting the yearning need of farm holders in harvesting operations as desired objectives.

2. MATERIALS AND METHOD

2.1. Functional Requirements of a Harvesting Tool

The functional requirements of a locally made fruit harvesting tool or implement include: climbing the tree; plucking the desired fruit; climbing down the tree, which requires lowering the implement to the ground level, packing the harvested fruits taken care of by the basket attached to the frame of the implement, thereby saving time for more fruit harvest.

2.2. Design Considerations

Lightweight; easy mobility; simple to operate; safety features; durable to withstand harsh conditions; longevity and improper usage; and affordability were the major design considerations.

2.3. Material selection and consideration

A galvanized steel circular pipe of 25mm and 12.5mm was used, respectively, to form the pole, to resist rusting when exposed to air and moisture. The galvanized sheet was used because of its high tensile strength, high compressive and shear strength, good ductility and malleability, toughness and hardness, good machinability, and high melting point. Other materials used include:

25mm diameter galvanized steel pipe of about 2743mm (9ft) in length; 12.5mm diameter galvanized steel pipe of about 2743mm (9ft) in length; 10 mm steel rod (mild steel); Nut and bolt; Plastic rope which was knitted to form the basket; Steel plate which was used to form a knife edge; Measuring tools; Electrodes; Hooks; Paint and Fusion 360 (CAD)

2.4. Implement description

2.4.1. Design of Citrus Harvester

Fig.1 shows the implement for harvesting oranges, mangos, and avocados while standing on the ground. The components of the implement include: a circular frame with a basket, a fan hook, a galvanized pole, and a bolt for regulating the height of the implement.

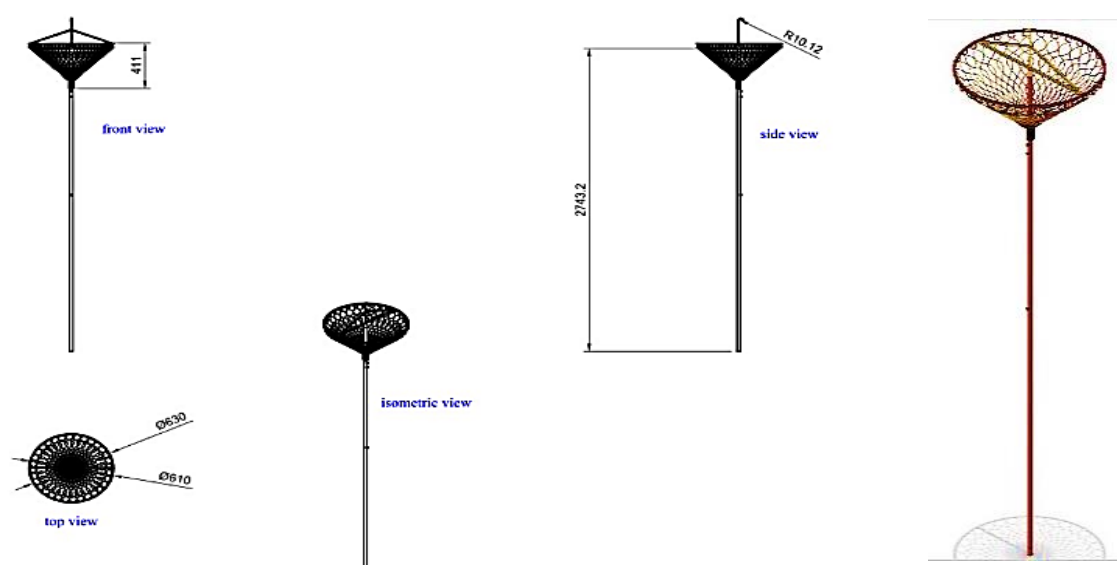


Figure 1: Schematic drawing of a citrus

2.4.2. Design of Circular Frame

The circular frame is the part of the implement designed for carrying the net into which the harvested fruit will fall. Considering the area of the frame that will not be large enough to cause interruption when going between branches, use the following calculations:

From the area of a circle:

$$(A = \pi r^2).$$

Where;

$$D = 630 \text{ mm}, \pi = 3.142, r = \frac{630}{2} = 315 \text{ mm}$$

Thus,

$$A = 311765 \text{ mm}^2$$

2.4.3. Design of the hook

The hook is the part of the implement that is responsible for pulling the fruits from their stalk. It takes the place of the human hand in ripping off fruits when on the tree. The hook is attached to the pole and then brazed to the circular frame with a square rod to increase the strength of the hook and prevent it from pulling off when force is applied. It has a rake angle of 15° . **Rake angle** is a parameter used in various cutting and machining processes, describing the angle of the cutting face relative to the workpiece

2.4.4. Nut and bolt

The nut and bolt are part of the implement, which were designed for height adjustment of the implement. The material for the nut and bolt is mild steel; it is chosen based on its tensile strength.

2.4.5. The torque

This is the force required to cause the rotation of the bolt and nut. A common relationship used to calculate the torque for a desired preload considers the thread geometry and friction in the threads and under the bolt head or nut. The following assumed standard for ISO or National Standard bolts and threads is used:

$$T = K P_{pre} d \quad (2.1)$$

Where: T is the required torque; P_{pre} is the desired preload; d is the bolt diameter; Nut factor

$$k = \frac{dm}{2d} \left(\frac{\tan \phi + \mu \sec \alpha}{1 - \mu \tan \phi \sec \alpha} \right) + 0.625 \mu_c \quad (2.2)$$

When $\mu = \mu_c = 0.15$, the dimensions used correspond to any size coarse or fine bolt, and the nut factor is $K \approx 0.20$, the torque/preload relationship becomes:

$$T = 0.20 P_{pre} d \quad (2.3).$$

2.4.6. Design of the basket

The basket is the component of the implement that is used in housing the harvested fruit and also preventing it from hitting the ground and getting bruised in the process. The basket material is made of a plastic knitted rope. The plastic rope was chosen because of its soft nature, and it cannot cause damage or bruising to the harvested fruit.

Because the basket has the shape of a cone, as shown in Fig. 2, we considered using the area of a cone to calculate the area of the basket.

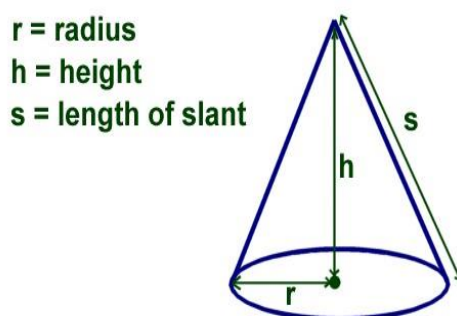


Figure 2. Area of the basket

The surface area of the basket is equal to the curved surface area plus the area of the base:

$$\pi r^2 + \pi L r,$$

where

$$r = \frac{D}{2} = 315 \text{ mm};$$

$$D = 630 \text{ mm};$$

$$\text{Height of the basket is } 430 \text{ mm}; \quad L = \sqrt{r^2 + h^2} = 533 \text{ mm}.$$

$$\text{Thus, } A = 839291 \text{ mm}^2$$

2.4.7. Tree crop harvester

Figs. 3 and 4 showed implements used for harvesting when on the tree top and the ground, respectively. This was designed because some of the trees are wild and have a height enough that the fruits cannot be harvested when standing on the ground. So, an implement was designed and fabricated for harvesting the above-mentioned fruits while sitting on any of the tree branches. The implement consists of a circular frame with a knitted net, which serves as the basket for packing the harvested fruit. It also has a light pole on which the circular frame is attached. Some fruits, like mango, do not require much force to be applied to the stalk before it disengages and falls off. To prevent the fruit from falling off and hitting the ground, the implement was designed in such a way that it has a semi-circular component where the hook is attached, so when the fruit disengages from the stalk, it falls on that platform and rolls into the basket. On the other hand, fruits like oranges require much force to be applied to the stalk before the fruit can disengage and fall off. Because a higher force is required, a semi-circular platform was also attached opposite the hook so that any fruit that tends to escape the basket would hit the platform and roll back into the basket.

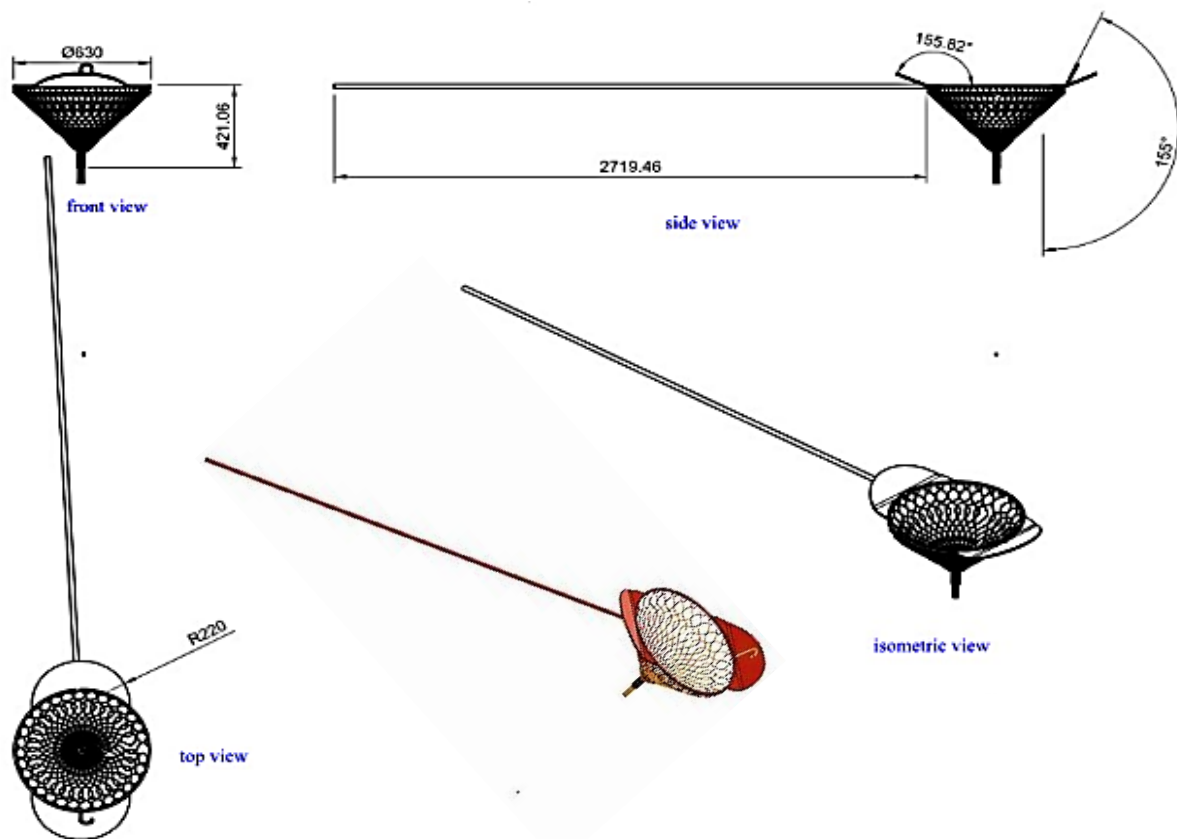


Figure 3: Schematic drawing of citrus harvester 2

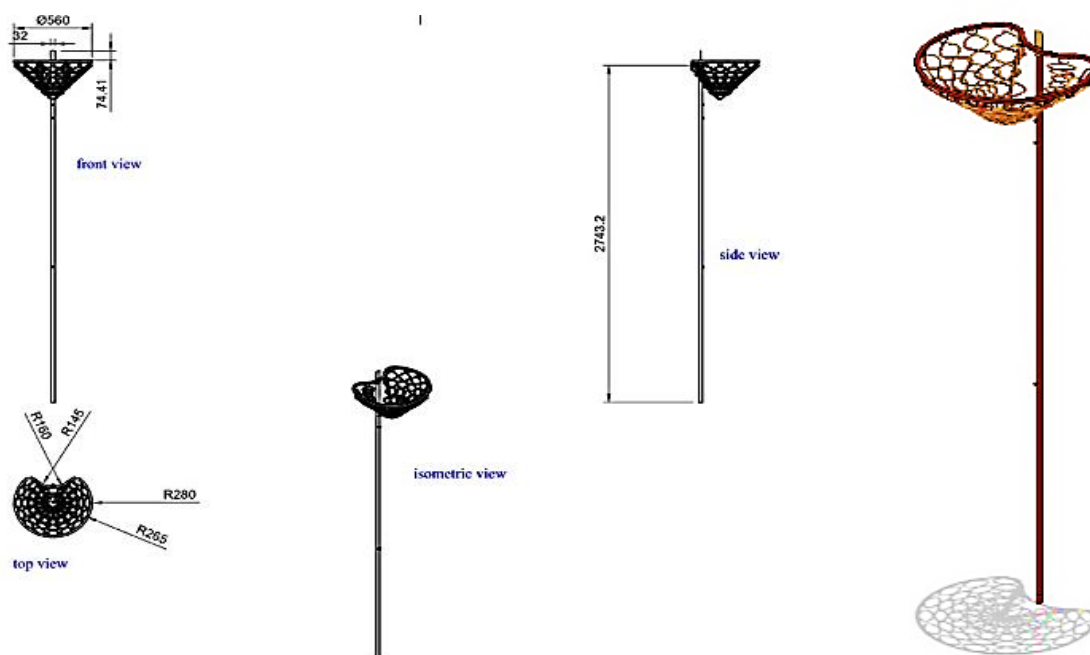


Figure 4: Schematic drawing of pawpaw and cocoa harvester.

2.5. Human Considerations

Based on the parametric designs to suit the human weight, the following were considered: (i) The maximum weight ratio of the implement and human body should not exceed the ratio 3:1, with the human body having the higher value. (ii) The human mass (considering an average adult in Africa) is about 60kg, and the average human weight (W_h) gives;

$$W = \text{mass} \times \text{gravity} = mg \text{ (N)}$$

$$W = 60 \times 9.81 = 588.6 \text{ N.}$$

(iii) For the implement, the weight of the implement is also derived in the same manner because the implements vary from one another, as shown in the human implement ratio.

In harvesting mangoes and oranges while on the ground, the measured value is 10.5kg; therefore, the weight of the implement (W_i) = $mg = 103\text{N}$.

Likewise, human - implement weight ratio W_{hir} (x) could be derived through the proportionality values thus; $103 = 1$; $588.6 = x$

$$103x = \frac{588.6}{103} \quad x = 5$$

which is an acceptable region for human energy dissipation and 83.4N for pawpaw and cocoa harvesting operation, with $W_{hir} = 7$ while harvesting on top of tree crop is 10 from proportionality value, $58.86 = 1$ and $588.6 = x$

$$x = \frac{588.6}{58.86} = 10.$$

Therefore, $W_{hir} = 10:7:5:1$ is in std for human crop harvesting operations.

RESULTS / TEST EVALUATION

When the implement is engaged with the stalk of the fruit and a brisk force is applied, the fruit is then pulled towards the direction of the operator, and it detaches from the stalk and falls off, called the pulling force. Fruits like oranges, mangoes, and avocados are harvested by applying a pulling force on the implement. The tool that pulls off the fruit from the stalk has the shape of a fan hook, which takes the place of a human hand. The pushing force is a force that is applied and acts away from the source of application. When the implement is engaged with the stalk of the fruit, a brisk pushing force is applied to the implement, which has a sharp blade that acts as a cutter. This force makes the blade cut off the stalk of the fruit from the stem, and the fruit falls off. The fruits that can be harvested using the pushing force include pawpaw and cocoa.

Test and Evaluations

The force required to pull the fruit from the stalk

On average, a farm worker (man) can develop 0.1 hp or 0.075 kW (Orja and Michael 2005).

Evaluating the implementation, the required force is shown below.

$$\text{Power} = \text{force} \times \text{velocity}$$

Force exerted for orange harvesting, given distance of hand travel = 500mm (0.5), time of pull = 3.65sec (0.00101hr), and velocity of pull = 495.049m/hr. Therefore, for an 8-hour work shift, an average healthy, well-fed, and motivated manual laborer may sustain an output of around 75 watts of power (0.075kW). Thus, the force of the pull of the fruit from the stalk gives.

$$F_{p\downarrow} = x = \frac{\text{power}}{\text{velocity}} = \frac{0.075}{495.049} = 0.0002 \text{ N.}$$

Therefore, the force required to pull off the fruit from the stalk is 0.0002 N.

Human consideration when the implement is loaded

Determining the amount of load the implement can carry from small to large-sized citrus showed;

- Medium - sized weight (W) = 131 g = 0.131 kg = 1.3 N
- Large - sized weight (W) = 184 g = 0.184 kg = 1.8 N
- Small-sized weight (W) = 96 g = 0.096 kg = 0.94 N.

For each of these sizes, an average of 10 oranges was harvested and carried about to determine its effect on the person carrying it. When this was compared to the average human weight, it was discovered that the weight of the implement plus the load being carried cannot overcome human weight, and therefore, an average of 10 fruits is acceptable at a time.

4. CONCLUSION

From design, fabrication, testing, and evaluation, the implements for harvesting tree crops, e.g., mango, orange, pawpaw, cocoa, and avocado etc., were considered for the concept of “**Nguru**” used in villages. The functional requirement for good harvesting operation, thus the mechanical tree shakers as practiced in developed countries or the ‘Nguru’ local/cultural known implement, may not be encouraged to minimize early death of tree crop and immature crop harvesting operation. This research is recommended for further improvement by applying more automated devices, as this is a manual tool.

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