RESEARCH ARTICLE OPEN ACCESS

# Design, Construction and Performance Evaluation of A Coffee (*Coffea Arabica)* Threshing Machine

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**ABSTRACT**
Coffee ranks as one of the world's most valuable and widely traded commodity crops and is an important export product of several countries. The objective of this research is to design, construct and evaluate a machine for threshing coffee. The material of construction was selected based on strength, availability, durability and corrosiveness. The main component parts of the machine include: shaft (300 rpm and diameter 25mm), concave sieve (Ø 10mm), the threshing head, sieve and blower which was made from 1.5mm thick sheet metal. The moisture content of the coffee is determined in the laboratory using conventional oven drying method and computed to give the following moisture content: 4.6%, 9%, 13.8%, 6% and 8.4%, and a mean moisture content of 8.4% which were used in this evaluation. The shaft speed was kept at a constant speed of 300 rpm. Results show that the threshing efficiencies are 78%, 85%, 89%, 80% and 84% and the capacity of the machine in g/sec and g/min are 860.1g/sec, 963 g/sec, 954.1 g/sec, 943.4g/sec, 1183.5 g/sec and 14.30 g/min,16 g/min, 15.90 g/min, 15.70 g/min, 19.70 g/min respectively. The average threshing efficiency of the machine and the average capacity of the machine are 83% and 3532kg/hr (3.5tonnes/hr) respectively

***Keywords:*** Coffee**,** Threshing machine, Threshing Efficiency, Moisture Content and machine Capacity

## I. INTRODUCTION

Coffee (*Coffea arabica*) is a genus of flowering plants whose seeds, called coffee beans, are used to make coffee drink. It is a member of the *Rubiaceae* family. They are evergreen shrubs or small trees that grow approximately 5 m (15 ft) tall when unpruned. Coffee trees are native to tropical Asia and Southern Africa. Coffee ranks as one of the world's most valuable and widely traded commodity crops and is an important export product of several countries (Stoffelen *et al.*, 2008). The leaves are dark green and glossy, usually 10–15 cm (4–6 in) long and 6 cm (2.4 in) wide. The flowers are axillary, and clusters of fragrant white flowers bloom simultaneously and are followed by oval berries of about 1.5 cm (0.6 in). Green when immature, they ripen to yellow, then crimson, before turning black on drying. Each berry usually contains two seeds, but 5–10% of the berries have only one; these are called peaberries. Berries ripen in seven to nine months. *Coffea arabica* is predominantly self-pollinating and as a result, the seedlings are generally uniform and vary little from their parents. In contrast, *Coffea canephora*, *C. excelsa*, and *C. liberica* are self-incompatible and require outcrossing. This means that useful forms and hybrids must be propagated vegetatively. Cuttings, grafting, and budding are the usual methods of vegetative propagation. On the other hand, there is great scope for experimentation in search of potential new strains (Suarez and Beaton, 2003). Coffee production lies mainly in the hands of a large number of small farmers with few large private or state industrial plantations (Souza, 2008). The coffee seed, or "coffee bean," comes from the coffee berry, or "coffee cherry."Coffee is perhaps most prized for its caffeine content. The caffeine content in a cup of coffee varies widely depending on the type of bean used and the brewing method. While most of the caffeine is removed during the decaffeination process, trace amounts may still remain. The international standard for decaffeination requires that 97% of the caffeine be removed from decaffeinated coffee while the European Union’s standards require no less than 99.9% to be removed (FAO, 2006). Most methods of decaffeination follow the same basic principle: soak the beans in water, which allows the caffeine (and other chemicals responsible for flavour) to leach out of the beans. The extracted liquid is then either passed through a filter or mixed with a solvent to remove only the caffeine and leave the other beneficial compounds. The flavour rich, caffeine deficient solution is then re-introduced to the beans to allow the flavour to be reabsorbed **(**Pendergrast, 2001).

### 1.1 Post Harvest Handling of Coffee

***Coffee Preparation:*** this involves series of processes in turning coffee beans into beverage. Processing operation include four basic steps; roasting of raw coffee (transforms the chemical and physical properties of green coffee beans into roasted coffee products with an increase in size, color and density, Kummer and Corby, 2003), grinding (fineness of grind strongly affects brewing as it exposes coffee grounds to heated water during brewing, Kate, 2006), brewing (to create a beverage by mixing ground coffee with hot water long enough to extract the flavour. Manolis, 2006 reported that for most brewing methods, a burr grinder is deemed superior because the grind is more even and the grind size can be adjusted, coffee can be brewed in several different ways; decoction (through boiling), infusion (through steeping), gravitational percolation (known as drip brewing), or pressurized percolation (as with espresso) and finally separating the used grounds and the liquid coffee. Coffee is often vacuum packed to prevent oxidation and lengthen its shelf life **(**Metcalf and Allan, 1999).

There is need to reduce post-harvest losses, labour cost and high energy input and generally encourage coffee production in quality and quantity to meet international and market requirement, this calls for application of mechanical methods to coffee production **(**Weinberg *et al.*, 2001). Thus, the objective of this research work is to design, construct and evaluate a coffee harvesting machine.

## II. MATERIALS AND METHOD

**(i) Material Selection:** The materials used were obtained locally at Gate market in Ibadan, Oyo State, the materials were critically considered based on strength, availability, durability and corrosiveness to prevent machine damage, ease construction work and maintenance and prevent rusting or corrosion of the machine parts hence, mild steel angle iron was used for the frame and stainless steel for the threshing chamber

**(ii) Design Consideration and Analysis:** the pre-design stage included measurement of the physical and engineering properties of the crop to determine appropriate design parameters for the threshing operation. The decorticating and separation component were designed using relevant engineering principles and theories. The design concept involves the use of impact and frictional forces of rubber beaters against steel plate, lined with reinforced rubber strip to reduce crop breakage with reasonable power requirement. The design considerations included use of gravity and minimum friction to reduce power requirement, economy and ergonomics, machine efficiency and product quality, simple operational and maintenance requirements to meet the need of local farmers and small scale industrialist, portability and detachability for easy transportation and low grain damage.

**(iii) Component Parts of the machine:** The threshing machine could be divided into 7 major units including: the frame, threshing drum and concave, blowing fan, reciprocating screen, grain outlet, transmission system:

**a)** ***The Frame:*** this is the structural unit which carries the main load. It ensures rigidity and stability of the milling unit and serves as the base and support. The frame was designed to hold other various machine components in the relative and stable position for good operation. The forces of machine members acting on the field were considered. The frame, 800mm high, fabricated from angle mild steel has overall top dimensions of 320mm x 600mm with upright member spread out at the base for better stability as presented in Figure 1 and Plate 1:

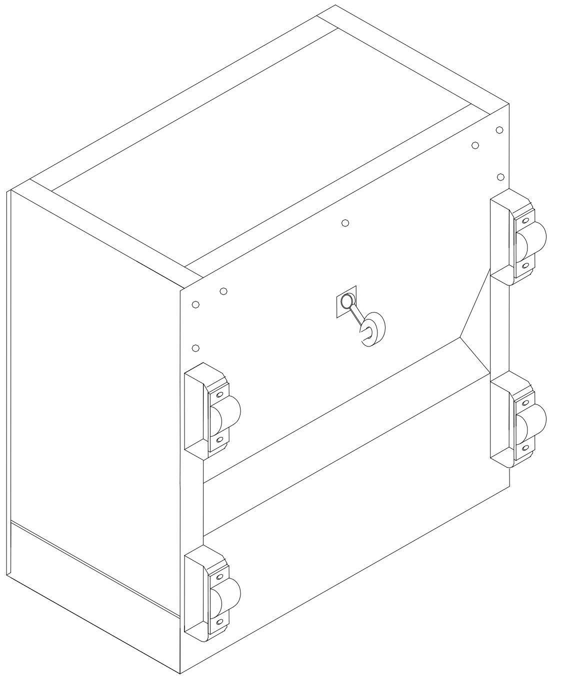

**Figure 1: The Frame Design**

**Plate 1: The Constructed Frame**

**b)** ***The Hopper and Perforated Outlet:*** The capacity, angle of repose of parchment coffee and space are important factors considered. A square frustum at the top and bottom respectively, with each side inclined at 45° to the horizontal is welded on a 100mm high square box placed to one end of the circumference of the threshing drum cover. The hopper was also incorporated with a feed cover regulating slide which is adjustable through a bolt. The hopper was made up of mild steel plate with trapezoidal shape to serve as outlet for the material. It was designed such that materials to be grated fall on the auger with gravity. Perforated outlet was made up of stainless metal as shown in Figure 2

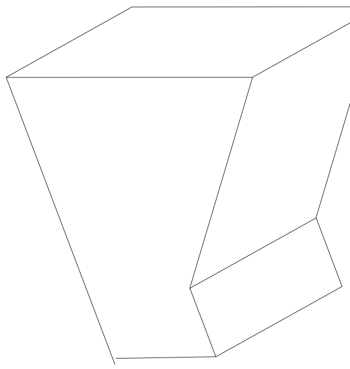

**Figure 2: The Hopper**

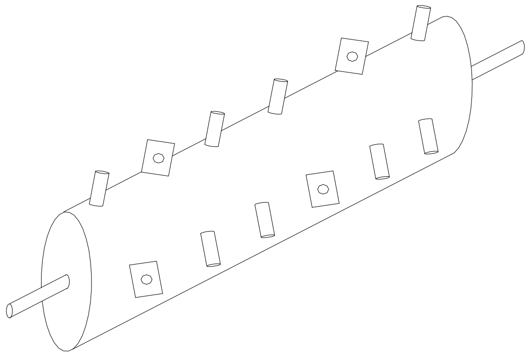

**Figure 3: Rubberized Threshing Drum**

**c)** ***The Threshing drum:*** The component consists of a hollow pipe, shaft and rubber flaps. One shaft 25mm in diameter is centrally welded to each of the pipe. 18 pieces of 5mm thick rubber flap were helically arranged in 3 rows on the circumference of the pipe. The rubber flaps are bolted to short pieces of 4mm thick metal plates welded to the circumference of the pipe. The drum rotate in perforated semi-circular concave constructed from 2mm sieve metal plate. The drum rotates inside the concave to detach the hull from the beans through impact and rubbing actions (Figure 3).

**d)** ***The Blowing Fan:*** A centrifugal fan is used because of the advantage of large air volume, high pressure at low power requirement. Using appropriate theories, the dimension of the fan were determined. The parameters considered at the air velocity and volume. The housing was also designed to appropriately contain the fan blades. Three fan blades of 300mm x 100mm were cut from 2mm plate are welded to the parameters of 25mm driving shaft. The air blast generated by the fan moves the hull and lighter materials while the beans and unthreshed coffee fall on the screen. The housing fabricated from 1.5mm thick plate consists of 2 circular disks of 260mm outer and 180mm inner diameter welded to each end of a rolled cylinder 400mm long. The top of the cylinder is extended to the cleaning chamber such that air stream is discharged horizontally over the cleaning screen (Figure 4).

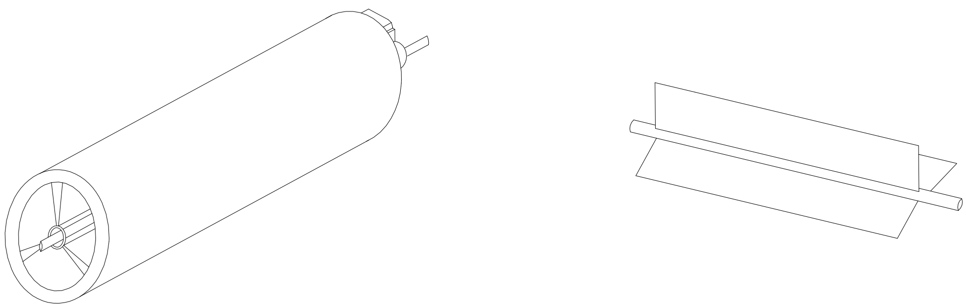

**Figure 4: The Fan Housing and Blowing Fan**

**e)** ***The Reciprocating screen:*** Considering the speed, the amplitude, the cleaning efficiency and field rate, the dimension of relevant parts were determined. The screen made from 2mm thick plate is supported by angle iron frame to each side of which two 16mm ball bearing was attached such that the cleaning screen is inclined at 0.5° to the horizontal and tilted to the front of the machine. The reciprocating unit consists of an eccentric cam carrying 25mm shaft so attached to the 50mm ball bearing to give 20mm throw of the screen. The screen slides to and fro inside a channel welded to the frame on either side of the screen (Figure 5)

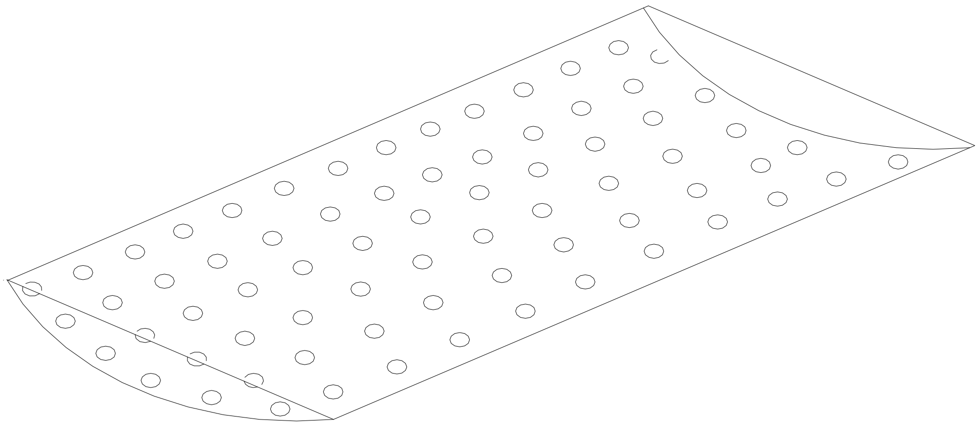

**Figure 5: Reciprocating Screen**

- **f)** ***The Grain Outlet:*** This is placed directly below the cleaning chamber to appropriately discharge threshed beans. It is 120mm x 80mm and inclined of 45° to the horizontal at lower end.
- **g)** ***Power Transmission System:*** The design is based on the power requirement of various component, economics and relevant theories. It involves the use of different sizes of pulley and length of V belts as dictated by the required speeds and power. Power transmission unit consist of rotor directly connected to the shaft of the grating machine. The machines consist of two bearings, which reduce the wearing and tearing of the auger and shaft. The bearing holds the auger in position and allows transmission of force.

**(iv)** ***Overall Design of the Machine*****:** The machine was developed from indigenous materials and could thresh parchment coffee and clean the beans simultaneously. The isometric, orthographic and component drawings of the thresher are shown in Figure 6 and Plate 2.

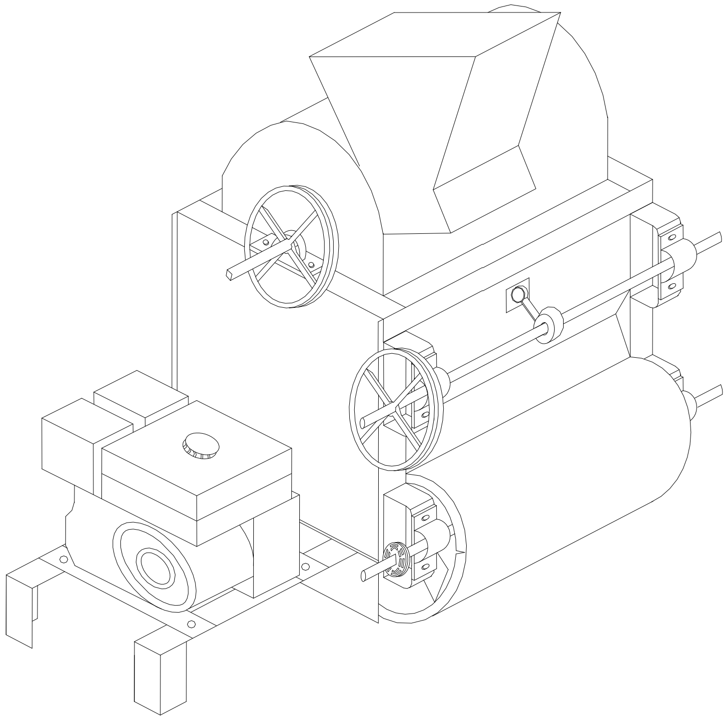

**Figure 6: Designed Coffee Threshing Machine**

**Plate 2: Front view of the Constructed Coffee Threshing Machine**

## III. Performance Evaluation of the Machine

The crop is loaded directly into the hopper as a prime mover is running. The feed regulating slide is adjusted to the appropriate position and the engine to the appropriate speed for optimum performance. Parchment coffee flowed under gravity to the dehulling unit where impact force of the rotating beaters remove the beans from the parchment through the combination of stripping, rubbing and impact actions. Threshed beans, unthreshed coffee, chaffs or parchment and foreign materials fall on the reciprocating screen through the concave. Horizontal and vertical displacement of the screen as it reciprocates causes the materials on it to move towards the front end of the machine. Air stream from the blower helps to disperse the bean to pass through the holes of the screen while the chaffs, parchment and lighter materials than the beans are blown off. The clean grains (beans) are collected through the grain outlet and the un-threshed beans and contaminants heavier than the beans fall through the front of the screen. The test carried out on the machine includes:

i. **Moisture Content**: The moisture content was determined using conventional oven drying method with the aid of an electric weighing balance, oven dryer, can and coffee seeds in accordance with ASAE Standard S358.2 (1983). The seeds were dried in an electric thermostat heated dry box (WH-43, India) a temperature of $103°C$ for 24 hours and computed on wet basis using Equation (1):

$$Mcwb = \frac{Wwp - Wdp}{Wwp} \quad ...(1)$$

Where:
$Mcwb$ is the Moisture content in wet basis,
$Wwp$ is the Weight of wet product (g) and
$Wdp$ is the Weight of dry product (g).

ii. **Threshing Efficiency**: computed using the equation given by Olaoye *et al.* (2010) as:

$$nT = 100 - \frac{Qu}{Qt}\, x\, 100 \quad ...(2)$$

Where:
$nT$ is the Threshing efficiency (%),
$Qu$ is the Quantity of unthreshed coffee seeds and
$Qt$ is theQuantity of threshed grain in sample

iii. **Capacity of the Machine**: The capacity of the machine is calculated by using the formulae:

$$Capacity\ of\ the\ machine = \frac{Mass\ of\ the\ output}{Duration\ \ of\ operation} \quad ...(3)$$

## IV. Results and Discussions

### 4.1 Result of preliminary Tests

The comprehensive result of the mean moisture content of the coffee seeds after oven drying showed the highest moisture content as 13.80% while the lowest moisture content is 4.60% as shown in Table 4.1.

**Table 4.1: Moisture Content of the Coffee Seeds**

| Trials | Mass of wet product (g) | Mass of dried product (g) | Moisture content (% wb) |
|---|---|---|---|
| 1 | 5 | 4.77 | 4.60 |
| 2 | 5 | 4.55 | 9.00 |
| 3 | 5 | 4.31 | 13.80 |
| 4 | 5 | 4.70 | 6.00 |
| **5** | 5 | 4.58 | 8.40 |
| **Sum** | 25 | 22.9 | 41.8 |
| **Average** | 5 | 4.58 | 8.36 |
| **S. D.** | 0 | 0.18 | 3.53 |

***S. D.= Standard Deviation***

**4.2 Performance Evaluation Results**

The result of the performance evaluation test of the dry coffee threshing machine is shown in Table 4.2. The pictures of the coffee before and after threshing are shown in Plate 3a and 3b.

*(a) Before threshing*

*(b) After threshing*

**Plate 3: Coffee Seeds**

**Table 4.2: Results of Performance Evaluation Tests**

| Trials | MbT (g) | *T m* (g) | Um (g) | Tt(min) | T*e* | Tc (g/min) |
|---|---|---|---|---|---|---|
| 1 | 3000 | 2460 | 540 | 2.86 | 78 | 14.3 |
| 2 | 3000 | 2600 | 400 | 2.7 | 85 | 16 |
| 3 | 3000 | 2700 | 300 | 2.83 | 89 | 15.9 |
| 4 | 3000 | 2500 | 500 | 2.65 | 80 | 15.7 |
| 5 | 3000 | 2580 | 420 | 2.18 | 84 | 19.7 |
| Average | 3000 | 2568 | 432 | 2.64 | 83.2 | 16.32 |
| S. D. | 0 | 93.4 | 93.4 | 0.27 | 4.32 | 2.01 |

***MbT** is the Mass before threshing, **Tm** is the Threshing mass, **Um** is the mass of unthreshed seeds, **Tt** is the threshing time, **Te** is the Threshing efficiency and **Tc** is the Threshing capacity*

**4.2.1 Threshing Capacity of the Machine (g/min)**

At moisture content range 4.6 -13.8% w. b, the threshing capacities of the machine ranges from 14.3-19.7 g/min with a mean value of 16.32 g/min (± 2.01) shown in Table 4.2. It was observed that the threshing capacity and threshing time are inversely proportional.

**4.2.2 Threshing Efficiency (%)**

At a mean moisture content of 8.4 %, the coffee seeds were perfectly threshed at an efficiency of 89% (Table 4.3). The threshing efficiency depends on the effectiveness of the rubberized threshing drum and the mass of the coffee induced into the threshing drum. From the result obtained, it can be deduced that the time of threshing has a negligible effect on the threshing efficiency of the machine. Similar trends were reported for the shelling efficiency of maize thresher with a shelling efficiency of 86 % (Nwakaire *et al.*, 2011), bambara groundnut sheller with a shelling efficiency of 80 % (Atiku *et al.*, 2004), melon shelling and cleaning machine with a shelling efficiency of 90 % (James *et al.*, 2011), groundnut sheller and decorticator with a shelling efficiency of 87% (Gitau *et al.*, 2013) and an electrically groundnut sheller with a shelling efficiency of 78% (Mohammed, 2010).

**4.3.3 Effects of Moisture Content on Threshing efficiency and Capacity**

As the moisture content of the coffee seeds increases, the threshing efficiency of the machine also increases however, the moisture content does not have any significant effect on the threshing capacity of the machine, this can be evidently seen in Figure 7.

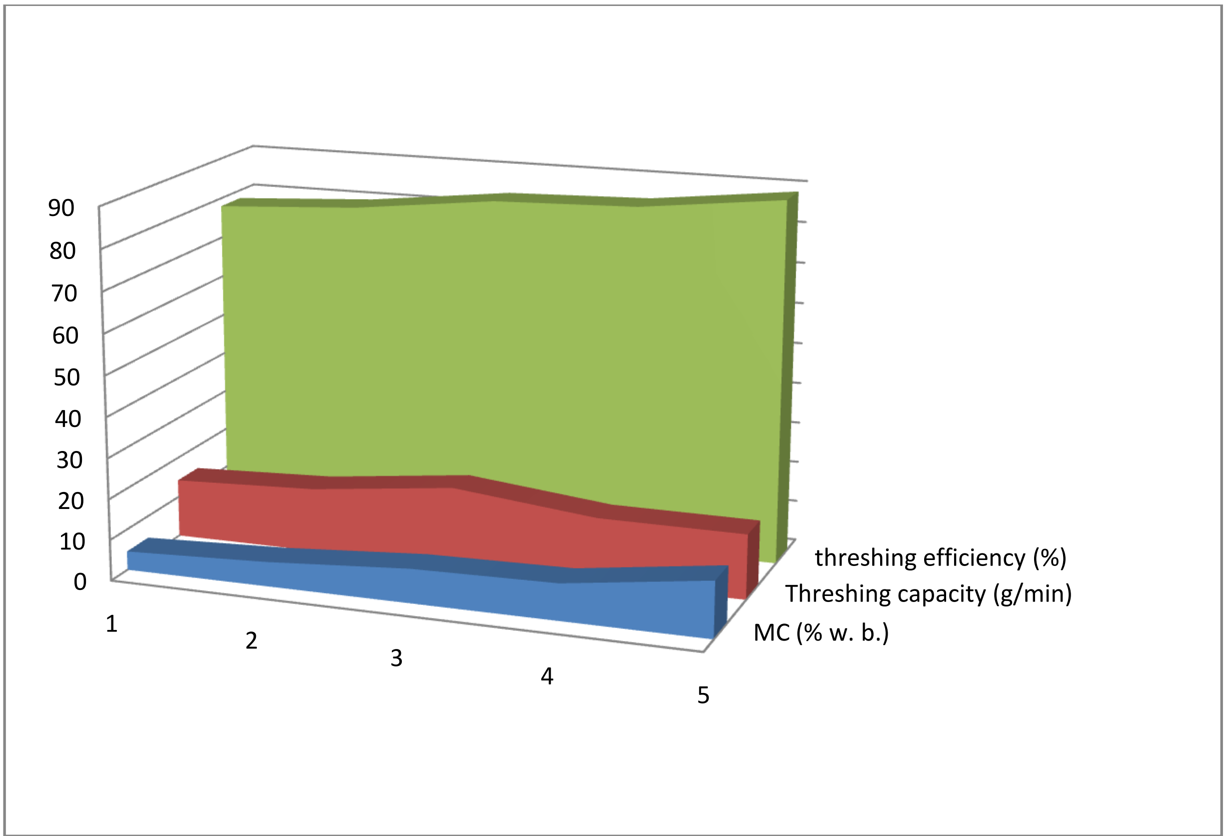


Figure 7: Relationship between Moisture Content, Threshing Efficiency and Threshing capacity

## V. Conclusions and Recommendation

**5.1. Conclusions**

A coffee seed threshing machine was developed and evaluated, the following conclusions were drawn:

i. The average threshing efficiency of the machine is 89% at a an average moisture content of 8.4 % wet basis and 300 rpm speed of rotation.

ii. The average threshing capacity of the machine is 16.32 g/min (± 2.01).

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