ISSN No:-2456-2165

Design, Construction and Performance Evaluation of an African Breadfruit Seed Dehulling Machine

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Abstract:- Dehulling of African breadfruit seeds is a difficult task and it requires more than 70% of the total time of operation in the processing of the seeds. However, it enhances and prolongs the shelf life of the seeds during preservation. A gasoline engine powered dehulling machine was designed, fabricated and tested. There is a noticeable impact of speed and time on the performance of the machine at the required 5% level of significance. 100% increase in both the speed and time of frying increases the performance efficiency by 1.2% and 11.7% respectively. As a result, a top speed of 1700 rpm gave a maximum efficiency of 79.79% while 1300 rpm gave a minimum performance of 73.19%. Moreover, it was found that as the dehulling speed and frying time increases, the seed breakage increases hence, decreasing the quality efficiency. The frying time of 20 minutes had performance ratio of 76.12% efficiency, 54.38% quality and 17.02% breakage; 30 minutes 79.43% efficiency, 71.73% quality and 19.58% breakage while 40 minutes had 80% efficiency, 58.49% quality and 48.97% breakage. Therefore, it can be concluded that the optimum frying time of African breadfruit seeds is 30 minutes.

Keywords:- *African Breadfruit, Seed, Frying Time, Speed, Efficiency, Dehuller.*

I. INTRODUCTION

African breadfruit *(Treculia africana)* tree is a multipurpose and medicinal plant species which belongs to the family Moraceae and order of Urticales (Okonkwo and Ubani, 2012; Nnamdi *et al.*, 2016). It grows in many parts of west and tropical African such as; Nigeria, Senegal, Uganda, Tanzania, Southwest Cameroon, Ghana and Sierra Leone. It is widely found in the forest zone, particularly the coastal swamp zone. Its seeds are commonly called ukwa in Igbo; afon in Yoruba; barafuta in Hausa; eyo in Igala; ize in Benin, Jekri and Sobo; izea in Ijaw; and ediang in Efik (Onweluzo and Odume, 2008).

Breadfruit is a great economic tree. From its leaves, fruits, stem to other parts of the tree such as the root, experts have found *T. africana* Decne and its other variants present in other parts of the world immensely useful in the treatment of many chronic ailments such as diabetes, acute Ischemia and hypertension (Oguntola, 2013). The seeds of the African breadfruit are of high nutritional value (Nwabueze and Nwokenna, 2006) and are currently a potential source of nutrients because of its immense contributions to the diet of the people of Nigeria (Okey and Clement, 2018)

Despite the high nutritional and medicinal value of the African breadfruit in the West and Eastern part of country, many rural people prefer to trade with other local fruits such as cashew nut, orange, tiger nut, walnut, kola to African breadfruit. This is due to the difficulties in the processing of the African breadfruit seeds from the whole fruit. According to Adumanya et al (2013), there is a lengthy and tedious operation associated with this process. It has high nutritional value, containing about 40% carbohydrate and 17% protein with several minerals and vitamins, and is a rich source of vegetable oil (Nnamdi et al., 2016)

A spongy pulp may house about 900 seeds (up to 18 inches) depending on the size of the fruit, and must be washed properly to remove an offensive odour that usually occur during the partial fermentation and decaying process of the fruit pulp. Thus, large volume of water is needed to wash the fruits clean. This operation is tedious and drudgery in nature. Dehulling of breadfruit is an essential aspect in the processing of the fruit to facilitate drying and preservation (Amiebenomo *et al.*, 2013). Thus, enhancing and prolonging the shelf life of the breadfruit. In any form the seed must be used, it has to pass through this particular process. Customarily, this is carried out manually with hands which are boring and time wasting. Processing of the seed into its kernel involves parboiling of the seed, cooling and manual removing of the hull (Okey and Clement, 2018). The seeds have two coats, the outer coat are usually harder and thicker than the inner coat. They are frequently removed by manual squeezing with hands or with a wooden or stone roller. This manual method makes the entire processing laborious and time consuming. This is why most people prefer selling out the washed seeds at this point.

Therefore, an African breadfruit seed dehulling machine, a mechanization system is designed and constructed to improve timeliness and precision of operation, reduce drudgery, increase the economic returns to the processors, improve the hygienic method of processing the seeds and increase the production yield of the breadfruits processing companies in the Southeastern part of the country.

II. METHODOLOGY

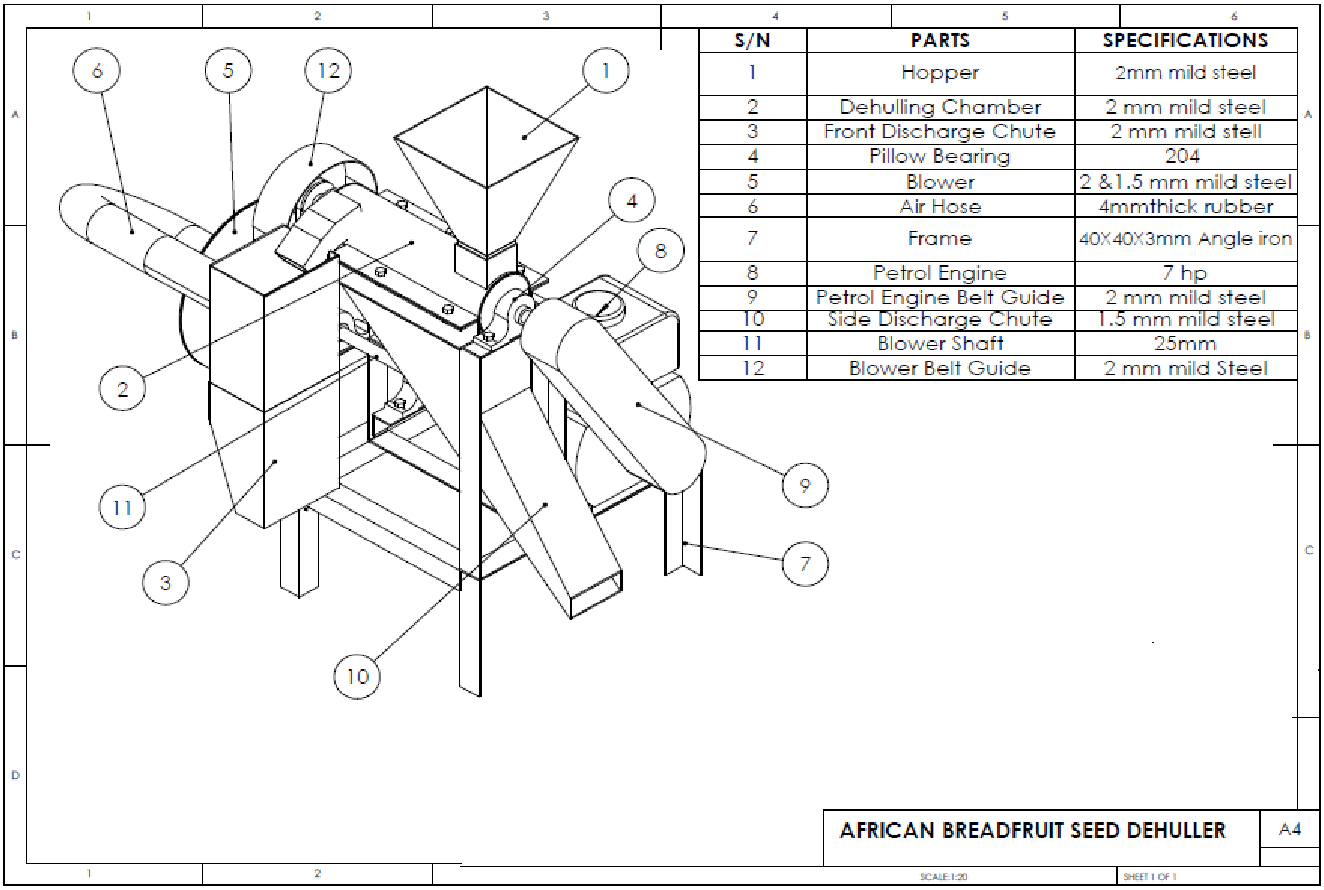
➢ *Design Considerations*

The machine was designed by taking into consideration the physical and mechanical properties of the African breadfruit seeds; geometric properties of the African breadfruit seed (length, width, thickness, geometric mean diameter, and sphericity), gravimetric properties (true density, bulk density and porosity) and frictional properties (angle of repose and static coefficient of friction) of the seed in order to achieve a good and acceptable efficiency.

The other significant parameters and variables carefully put into consideration during the fabrication of the machine include the following: strength of the material used, materials choice and selection, materials availability and affordability, selection of power unit and source of the dehuller, selection of the blower type of the machine, purchasing cost, operating cost and maintenance cost, capacity of the dehuller, and gender friendliness during the machine usage.

➢ *Description of the Machine*

The dehuller was fabricated with 1.5 and 2 mm mild steel plates, 19 mm mild steel shaft, 204 pillo bearing, 4" galvanized pipe thick, and angle iron of 40 x 40 x 3 mm. While the overall dimension of the machine is 480 x 350 x 660 mm. The volume of the hopper is 6.0 liters and can contain 5 kg of breadfruits. The dehulling unit/chamber was constructed to accommodate 3 kg of the seeds per dehulling batch. The dehulling unit was built to house a cylindrical pipe which is called dehulling drum with dimension of 120 mm diameter and 340 mm length of shaft. This drum is aligned with four wooden worms of 320 x 24.5 mm each. The worms are 10 mm spaced from each other. The centre of this dehulling drum is coupled with 19 mm mild steel shaft. The whole weight of these systems both the hopper and dehulling unit was formed to rest on the rigid frame of mild steel angle iron (see figure 1 – 2). The machine is powered by a 5.5 hp speed adjustable gasoline engine.



S/N	PARTS	SPECIFICATIONS
1	Hopper	2mm mild steel
2	Dehulling Chamber	2 mm mild steel
3	Front Discharge Chute	2 mm mild stell
4	Pillow Bearing	204
5	Blower	2 &1.5 mm mild steel
6	Air Hose	4mmthick rubber
7	Frame	40X40X3mm Angle iron
8	Petrol Engine	7 hp
9	Petrol Engine Belt Guide	2 mm mild steel
10	Side Discharge Chute	1.5 mm mild steel
11	Blower Shaft	25mm
12	Blower Belt Guide	2 mm mild Steel

Fig 1:- 2D Isometric View of the Dehuller

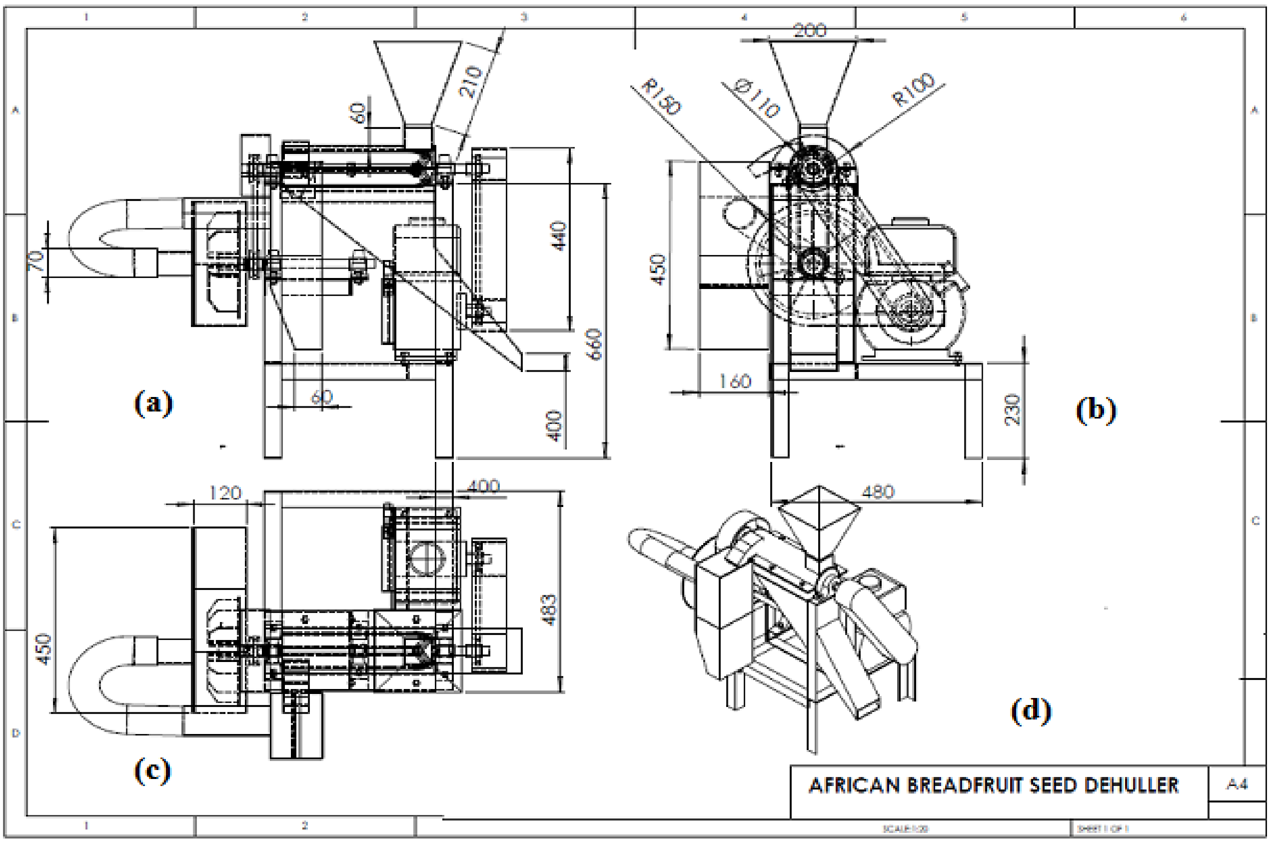


Fig 2:- The Front (a), Right Side (b), Plan (c) and Isometric View (d) of the Dehuller

➢ *Functional Component Parts of the Machine*

- *The Hopper*

This component part serves as a storage container for the agricultural materials (seeds) to be dehulled. It provides a passage way to the dehulling unit. The overall dimension of the hopper is 200 x 200 mm top and 58 x 58 mm down (figure 3).

In designing the hopper, the angle of inclination of the hopper walls of 10º higher than the natural angle of repose of the stored material (breadfruit seeds) was used (Richey *et al.*, 1961). This is to avoid tunneling and arching during the discharge of the breadfruit seeds.

The angle of repose of the breadfruit obtained experimentally by Etoamaihe and Ndubeze, (2010) is 28.6º. Therefore, angle of inclination of 39º was dimension used during the construction of the hopper. The shape of the hopper is like that of a frustum of a pyramid (Etoamaihe and Ndubeze, 2010). The volume of the hopper is 6.0 liters and can contain 5 kg of breadfruits.

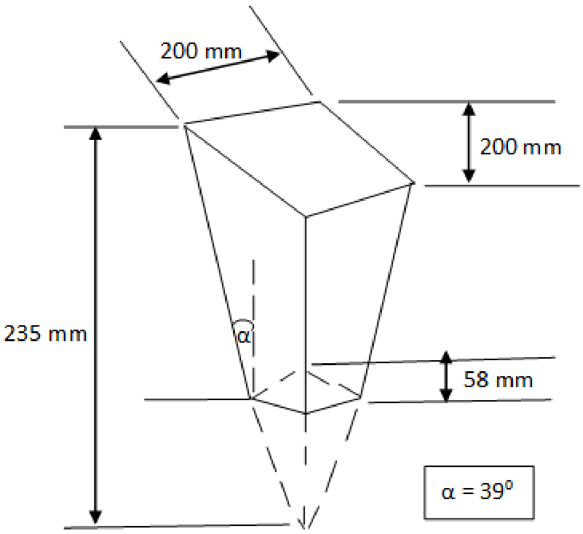


Fig 3:- 2Dimensioal Drawing of the Hopper

ISSN No:-2456-2165

- *The Dehulling Chamber*

This is a drum-like compartment which has two important sections; the top and the bottom case. The top part is made with 2 mm mild steel sheet folded in U-shape upwardly and its two side edges that seat on the frame of the dehuller are made with 24.5 mm flat bar. The top case of the chamber has an opening of 60 x 60 mm squared part that receives 58 x 58 mm base of the hopper. It also has a narrow outlet that pushes the seeds into the discharge chute. While the bottom case is made up of a stainless-steel mesh of 2.5 mm folded as well in U-shape downwardly which allows the passage of the dusty debris out of the dehulling system. The whole unit (both the top and bottom case) houses the dehulling drum which is made up of the 19 mm mild steel shaft, 80 mm cylindrical thick pipe (4" diameter) and plywood of 49 mm thickness used as the dehulling auger. The two ends of the 19-mm shaft are supported by 204 pillo bearings which allow the rotation of the shaft. The two ends of the shaft are connected to two sets of pulleys. The first pulley is connected to the gasoline engine via an A-43 belt while the second pulley has its connection to the blower mechanism with the help of an A-26 belt. In selection of diameter of the shaft used, the equation below by Shittu and Ndirika (2007) was used;

$$d = \left[\frac{16}{\pi s}\sqrt{(K_b\, M_b)^2 + (K_t M_t)^2}\right]^{\frac{1}{3}}$$

Where, M_b =Maximum bending moment on shaft (Nm) = 17.19 N/m; M_t = Maximum torsional moment on shaft (Nm) $\approx 2.35\ Nm$; K_b = Dimensional combined and fatigue factor applied to bending moment = 1.5; K_t = Dimensional combined and fatigue factor applied to torsional moment = 1.0; S_x = Allowable shear stress for steel 40×10^6 N/m^2 (ASME code)

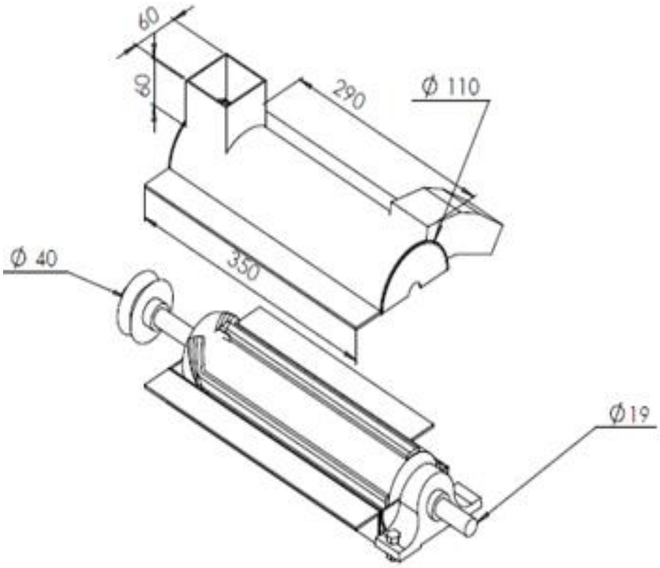


Fig 4:- 2D Drawing of the Dehulling Chamber

- *The Blower*

An L type of impeller was used during the construction to provide the sufficient mass flow rate of air needed. The impeller has 7 segments of vanes each with a dimension of 100 x 80 mm. A mild steel shaft of 19 mm was used to drive the entire impeller. The overall dimension of the blower is as follows: internal diameter, 20 mm; external diameter, 300 mm; length of the blower chamber 300mm; volute length, 100 mm and the discharge end, 100 x 100 mm (see figure 5). The blower has diameter hole of 47 mm which receives a galvanized pipe of 49 mm. This is the channel that connects the entire blower system to the separation unit (front discharge chute). Having the following design parameters; Vane Angle, $\beta = 67^o$, Volute radius, r = 0. 05 m; Vane Width at the Suction Eye, b = 0.08 m; Rotational speed of the engine, N = 2400 rpm; Area of the discharge end of the blower, A = 0.01 m^2, the equations below by Adekunle et al (2008) were used to estimate the flow rate which is 0.7447 m^3/s and the discharge capacity is 74.4m/s. This is why the output of the blower is very efficient.

The linear Speed at the inlet is;

$$U = r \times \omega$$

$$r \times \omega = r\, x\, \frac{2\pi N}{60}$$

$$V_1 = U \tan\beta$$

The expected flow rate is

$$Q = 2\,\pi\, r\, V_1$$

Applying continuity concept at the blower discharge

$$V_2 = \frac{Q}{A}$$

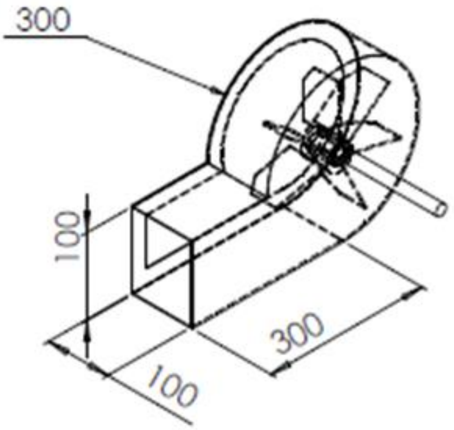


Fig 5:- 2D Drawing of the Blower

➢ *The Discharge Chutes*

This section of the machine is divided into two different parts. The "front" and "side" discharge chutes. The "front" discharge chute is the unit where the winnowing or separation operation takes place and the place where the dehulled beans are collected from. The outer part and internal parts of this unit are made with 2 mm and 1.5 mm mild steel plates respectively. The internal part contains four pieces of rectangular plates each with a dimension of 120 x 60 mm, tilted in position to form interposing partitions. This helps to reduce the free flow of the seeds as they come out with force directly from the dehulling unit into the discharge chute. This principle increases the efficiency of separation due to the delay and agitation of the seeds within the discharge compartment. The overall dimension of the "front" discharge chute is 450 x 200 x 100 mm. It anchors a galvanized pipe of 58 mm on its side part which receives 4 mm thick rubber air horse connected to the blower unit. The "side" discharge chute is a long and narrow compartment that protrudes to the side part of the machine. It collects the dusty particles coming out from the base of the dehulling unit and discharges them out of the machine. The dimension of the "side" discharge chute is 700 x 106 mm.

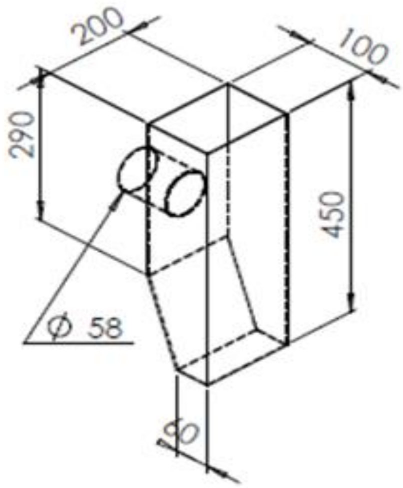


Fig 6a:- 2D of the 'Front' Discharge Chute

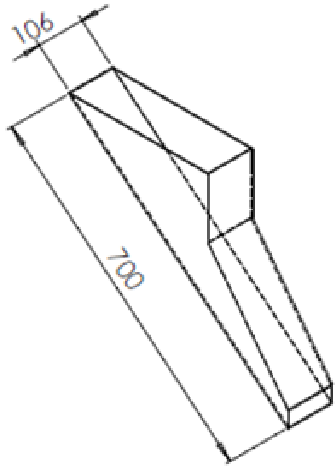


Fig 6b:- 2D of the 'Side' Discharge Chute

➢ *Pulley and Belt Size Determination*

- *The Pulley*

88 mm diameter of pulley was used. In estimating this size of the pulley, the equation below by Aaron (1975) was used.

$N_1D_1 = N_2D_2$

Where,

N_1 = speed of driven pulley (rpm) = 1200 rpm (speed required at dehulling unit)

N_2 = speed of driving unit (rpm) = 1500 rpm; D_1 = diameter of driven pulley (mm) =110 mm

D_2 = diameter of driving pulley (mm) =?

- *The Belt*

The V-belt size of A-43 was used and this length of belt was calculated using Khurmi & Gupta's equation (2004) as follows:

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C}$$

Where,

L= length of belt (mm); D_1 = 88 mm; D_2 = 110 mm.

C = distance between the centre of driving and the pulleys = 420 mm

III. PERFORMANCE EVALUATION

➢ *Sample Preparation*

African breadfruit seeds (*Treculia Africana* Decne) were selected for this study. About 100 kg of the fresh seeds was purchased from Eziora Ozubulu, Anambra State, Nigeria. The experiments were designed to manually sort the seeds with hands to remove the spoilt seeds and unwanted debris from the good sample to be tested. After the sorting, small quantity of about 20 kg was taken and divided into four different samples of 5 kg each for the determination of the average moisture content (MC) of the seeds. The moisture content was determined according to the ASAE S410.1 method (ASAE, 1998) and expressed as dry basis percentage (%, d.b). The seeds were prepared by roasting each sample of 5 kg for 20, 30 and 40 minutes normally as one of the local routine processing methods that African breadfruit seeds processors usually adopt during the processing.

➢ *Performance Test*

To determine the performance efficiency, quality efficiency and capacity of the dehuller, an experiment was conducted using five kinds of level of speed such as 1300, 1400, 1500, 1600, and 1700 rpm from the driving unit.

- *Performance Efficiency, P_e*

$$P_e = \frac{Mass\ of\ dehulled\ seed/bean\ (kg)}{Total\ Mass\ of\ breadfruit\ fed\ into\ the\ machine\ (kg)} \times 100$$

- *Quality Efficiency, Q_e*

$$Q_{e} = \frac{qauntity\ dicharge - destroyed\ (kg)}{quantity\ of\ breadfruit\ fed\ into\ the\ machine\ (kg)} \times 100$$

- *Breakage Efficiency, $\tilde{\eta}_{eb}$ (%)*

$$\tilde{\eta}_{eb} = \frac{M_{cb} + M_{pb}}{M_b} \times 100$$

Mass of the bean completely cracked but broken = M_{cb} ; Mass of the bean partially cracked but broken = M_{pb} Mass of the seed fed into the machine = M_b

- *Capacity of the Dehuller, C_d*

$$C_d = \frac{Mass\ of\ breadfruit\ fed\ into\ the\ machine\ (kg)}{Time\ taken\ to\ dehull\ the\ breadfruit\ (hr)}$$

Data Analysis: The whole experiments were analyzed using SPSS and STATA statistical software.

IV. RESULTS AND DISCUSSION

Coefficients[a]									
Seed	Model	Unstandardized Coefficients		Standardized Coefficients	T	P-value	F-statistic	R-square
		B	Std. Error	Beta				
Fried	Constant	55.154	3.283		16.801	.000	23.413 (0.000)	0.796
	Speed (rpm)	.012	.002	.784	6.012	.000		
	Time (min)	.117	.036	.426	3.268	.007		
a. Dependent Variable: EFF (%)								

Table 1:- The Regression Analysis of the Machine's Efficiency for the Fried Seed Samples

Seeds			EFF (%)	Speed (rpm)
Fried	EFF (%)	Pearson Correlation	1	0.784**
		Sig. (2-tailed)		0.001
		N	15	15
	Speed (rpm)	Pearson Correlation	0.784**	1
		Sig. (2-tailed)	0.001	
		N	15	15
	Time (mins)	Pearson Correlation	0.426	0.000
		Sig. (2-tailed)	0.113	1.000
		N	15	15

Table 2:- Correlation test Result for the Dehulling Efficiency

The effects of the individual and joint speed and time of frying on the performance efficiency of the dehuller adopted for the fried seeds were shown in Table 1. It was noticeable that both the speed and frying time have optimistic and considerable effect on the efficiency of the dehuller. It was established that 100% increase in both the speed and frying time caused an increase in the efficiency by 1.2% and 11.7% respectively. The coefficient of determination (R^2, 0.796) indicated that the two variables explained 79.6% of the variance in machine performance.

The correlation test result of the performance as a function of speed of the dehuller and the frying time of the fried seeds is as shown in Table 3. The result obtained showed that there was a high, optimistic and significant relationship between performance efficiency obtained and dehulling speed. The correlation value is 0.784 and p-value is 0.001. Hence, increase in speed of the dehuller will give higher efficiency at 5% level of significance. The figure 7 gives the pictorial view of the result, showing the direct trend of this increase; dehulling speed of 1700 rpm has the highest efficiency of 79.79% while the lowest performance efficiency of 73.19% was obtained at the speed of 1300 rpm. The effect of the speed on the dehulling machine is very crucial. This is what so many related African breadfruit fabricators usually fail to consider during the design. Like Nnamdi et al (2016) claimed to have obtained a result of 86% efficiency with a 250 rpm which was not tried on another speed level while Okey and Clement (2018) did not consider the speed as a performance evaluation parameter. Rpm is a function pulley used.

More so, from the analysis of the results, it was observed that the quality efficiency decreases with increase in dehulling speed, frying time and seed breakage. It was further observed that the best dehulling speed and frying time for dehulling African breadfruit seeds were 1500 rpm and 30 mins respectively. The frying time of 20 mins had 76.12% performance efficiency, 54.38% quality efficiency and breakage efficiency of 17.34%, while at 30 mins were has 79.02% performance efficiency, 71.73% quality efficiency and 19.58% breakage efficiency. However, as reported by Etoamaihe and Ndubueze (2010), frying at 40 mins resulted in 80% performance efficiency, 58.49% quality efficiency and 48.97% breakage efficiency. Therefore, this is an improved dehulling machine because when compares with Etoamaihe and Ndubueze's dehuller, it reduces the frying time of the seeds by 10 mins, increases quality efficiency by 13.24% and reduces the breakage efficiency by 29.39%. Although, according to Nnamdi et al (2016), their machine obtained a dehulling of efficiency of 86% when compared to ours (80%), but their throughput was found to be low, 216 kg/hr against 600 kg/hr of our machine. A higher efficiency is also possible with this very dehulling machine if the dehulling augers are changed to "tephelons" rubber-like materials.

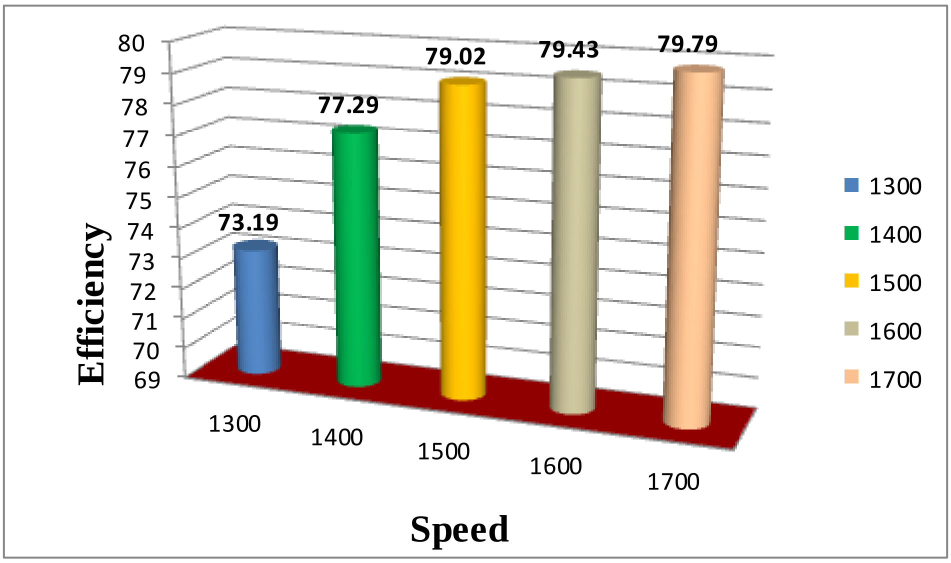


Fig 7:- Efficiency as a function of dehulling Speed

As shown in Figure 8, the undehulled mass was observed to be a function of the operating speed. As the speed of the dehuller increases the mass of the undehulled seeds decreases and was zero at the highest speed of 1700 rpm. In other words, as the speed of operation increases, the percentage of the dehulled mass increases.

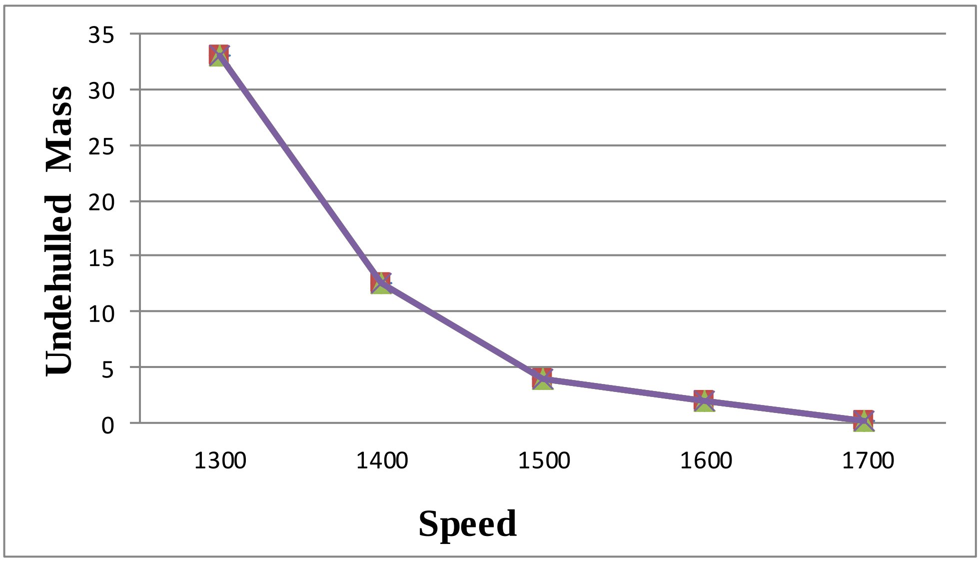


Fig 8:- Undehulled Mass against Dedulling Speed

ISSN No:-2456-2165

V. CONCLUSION

A Locally sourced material of an African breadfruit seed (*Treulia Africana* Decne) dehuller with a throughput of 600 kg/hr and efficiency of approximately 80% was developed. The machine works optimally at 30 minutes frying time and 1500 rpm operating speed. This machine gave the highest processing capacity among all the African breadfruit dehulling machines available in the country and its efficiency gave good quality dehulled seeds. Thus, it is recommended for commercial businesses to boost the processing of dehulled African breadfruit seeds in the country.

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