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Performance Evaluation of an Improved Roasted Groundnut Seeds Decorticating Machine

[1*]Orhorhoro, E.K., [2]Odinikuku, E.W., [3]Salisu, S.

[1]Department of Mechanical Engineering, Igbinedion University, Okada, Edo State, Nigeria.
(ejiroghene.orhorhoro@iuokada.edu.com)
[2]Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria.
(odinikukuwilly@gmail.com)
[3]Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria
(sulaimansalisu@gmail.com)

**Corresponding author: Orhorhoro, E.K., ejiroghene.orhorhoro@iuokada.edu.com (+2348064699781)*

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Abstract: *In this research work, an improved roasted groundnut seeds decorticating machine was successfully designed and fabricated. The major components of the machine were as follows; feed hopper, bearing, collection tray, pulley, V-belt, electric motor, frame, cloth conveyor, rollers, rectangular mild steel plate embedded with foam, bearing and shaft. The roasted groundnut seeds were fed to the machine through the feed hopper, where it settled in a stationary rectangular plate material produced from mild steel material that is embedded with foam underneath it. The cloth conveyor materials move with the help of shaft roller driven by the electric motor and the stationary. When the roasted groundnut seeds come in contact with these two members, decorticating takes place as a result of friction. Ten batches of roasted groundnut seeds of different masses were used to evaluate the designed machine for performance. Time required to completely decorticate the roasted groundnut seeds were recorded and this was used to determine the machine throughput capacity. The results obtained show that a 2hp power electric motor and a torque of 83.67Nm were required by the machine. Besides, an average efficiency of 84.44%, average decorticating time of 122.797seconds, and machine throughput capacity of 0.1204kg/s were recorded. The machine performance was satisfactorily and can replace the traditional method of decorticating roasted groundnut seeds in developing countries.*

Keywords: *Decorticating, Roasted groundnut seeds, Machine, Efficiency, Time, Machine throughput capacity*

Nomenclature

B_b	Breadth of foam (m)
C	Centre to centre distance between driver pulley and driven pulley (mm)
C_r	Radial factor
C_t	Thrust factor
D	Diameter (mm)
D_1	Diameter of the driver (mm)
D_2	Diameter of the driven (mm)
F	Force (N)
F_e	Equivalent dynamic load (N)
F_r	Radial load (N)
F_t	Thrust load (N)
g	Acceleration due to gravity (m/s^2)
h	Height of bearing housing (m)
H_h	Foam thickness (m)

H_t	Plate thickness (m)
L	Length of the paddle (m)
L_{10}	Basic dynamic life of the bearing (milli. rev.)
L_f	Life of the bearing = 18,000 ≤ 22,000 (hours)
L_L	Length of foam (m)
$M_{(DG)}$	Mass of decorticated groundnut seeds
M_G	Mass of groundnut seeds (kg)
$M_{(RG)}$	Mass of roasted groundnut seeds
MTC	Machine throughput capacity
N	Speed in revolution per minute
N_1	Speed of the driver (rpm)
N_2	Speed of the driven (rpm)
P	Power to turn the shaft (Watts)
Q	Determining factor
r	Radius of bearing housing (m)
S_f	Safety or service factor
T	Torque (Nm)
T_D	Time required to decorticate roasted groundnut seeds
T_1	Tension in the tight side of the belt (N)
T_2	Tension in the slack side of the belt (N)
V	Volume of peeling chamber (m^3)
V_B	Volume of bearing housing (m^3)
V_C	Volume of decorticating chamber (m^3)
V_F	Volume of foam lagging (m^3)
V_H	Volume of hopper (m^3)
V_P	Volume of plate (m^3)
x	Rotational factor
ρ_G	Density of groundnut seeds (kg/m^3)
α	Angle of wrap of an open belt (rad.)
α_1	Angle of lap for driver pulley (rad.)
α_2	Angle of lap for driven pulley (rad.)
μ	Coefficient of friction

INTRODUCTION

Groundnut (Arachis hypogaea) is the 6th most important oil seed crop in the world (Ebunilo *et al.*, 2016). It contains 48-50% oil, 26-28% protein, 11-27% carbohydrate, minerals and vitamin (Ogunwole, 2013, Pradhana *et al.*, 2010). Groundnut (Arachis hypogaea) is widely consumed and utilized industrially all over the world. Groundnut plays an important role in the diets of rural populations, particularly children, because of its high contents of protein and carbohydrate. It is also rich in calcium, potassium, phosphorus, magnesium and vitamin E. Groundnut meal, a by-product of oil extract, is an important ingredient in livestock feed (Ajav and Olatunde, 2011). Groundnut is grown on 26.4 million hectare worldwide, with a total production of 37.1 million metric tons and an average productivity of 1.4 metric tons/ha (Ugwuoke *et al.*, 2014, Oteng-Frimpong *et al.*, 2017). Developing countries constitute 97% of the

global area and 94% of the global production of this crop (FAO 2011, Kale *et al.*, 2011). Nigeria is the third largest producer of groundnut in the world after China and India with a production of 16,114,231, 6,933,000 and 2,962,760 tons respectively in 2011 (Gitau *et al.*, 2013, Ebunilo *et al.*, 2016). In Nigeria, the leading producing states include Niger, Kano, Jigawa, Zamfara, Kebbi, Sokoto, Katsina, Kaduna, Adamawa, Yobe, Borno, Taraba, Plateau, Nasarawa, Bauchi, and Gombe States (FAO, 2011).

The demand for groundnut is high and this is due to its domestic and industrial uses. However, the post-harvest processing of the food crop which also involves its decortication has been done in conventional and inefficient ways which results in large quantities of groundnuts being lost. In Nigeria groundnut is mainly decorticated by hands (Traditional method). This technique is a conventional technique that is as old as the existence of the food crop itself and man. It involves holding the roasted groundnut seeds in between the palm or fingers and rubbing slightly against the palm or against multiples nuts enclosed within the hand thereby impacting frictional force against them and removing the peels which are simultaneously or later blown off with the help of atmospheric air or air blown from the mouth of the individual who is performing the task. The output got from this method is very low

and it does not fulfill the market demand because it is a time consuming process. Mechanization is necessary and prevalent in the modern day world especially where accuracy, reduction in human labour, hygiene and increase in production output amongst other benefits has become paramount. Besides, the need to optimize production process at low financial and human cost in addition to promoting hygiene has prompted the intensive and extensive research into developing an improved technology for decorticating groundnut. The decorticating of roasted groundnut seeds is a crucial phase in the general processing of groundnut. Mechanization of groundnut decortication will not only help in reducing the labour involved in peeling groundnut manually but it will as well increase production.

MATERIAL AND METHODS

DESIGN REQUIREMENT

Establishing design requirements is one of the most important elements in the design process and this task is normally performed at the same time as the feasibility analysis. The design requirements control the design of the project throughout the design process. The following design requirements were drawn:

i. Estimation of power required by the groundnut decorticating machine (watts)
ii. Determination of approximate length of the belt (m)
iii. Determination of load on shaft pulley and belt tensions (N)
iv. Determination of speed of driver and driven pulley (rpm)
v. Determination of torque transmitted by electric motor (Nm)
vi. Determination of force require to decorticate the roasted groundnut (N)
vii. Selection of bearing diameter for shaft (mm)

DESIGN CONSIDERATION

To achieve optimum function for this machine, proper considerations were made to specify and identify some problems which could hinder the effective performance, as recorded in existing machines. Effort was put to identify the factors and constraints, as put together below.

i. Functionality
ii. Reliability
iii. Durability
iv. Materials and labour use
v. Portability and space
vi. Operational procedure
vii. Maintenance
viii. Cost
ix. Safety

DETAILED DESIGN

A. Determination of Weight of Groundnut Seeds

The weight of groundnut seed is calculated from Equation (1) as follow:

$$W_G = M_G \times g \quad (1)$$

But;

$$M_G = \rho_G \times V \quad (2)$$

Equation (1) becomes:

$$W_G = \rho_G \times V \times g \quad (3)$$

B. Determination of Volume of Decorticating Chamber

Volume of the decorticating chamber is calculated as follows:

$$V_C = V_{H-}V_{F-}V_B - V_p \quad (4)$$

C. Volume of Hopper

The volume of housing was calculated as follow:

$V_H = \frac{1}{2}(a+b)H_h$ (m^3) (5)

D. Volume of Foam Lagging

The volume of foam lagging was calculated as follow:

$V_F = L_L \times B_b \times H_t$ (m^3) (6)

E. Volume of Bearing Housing

The volume of bearing housing is given by Equation (7):

$V_B = \pi \times r^2 \times h$ (7)

F. Volume of Plate

The volume of plate is given by Equation (8):

$V_P = 2(L_P \times B_P \times H_t)$ (8)

G. Determination of Belt Length

The belt length was obtained as follow:

$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1+D_2}{4C}$ (Khurmi and Gupta, 2013) (9)

G. Distances between Driver and Driven Pulley

The centre to centre distance between driver and driven pulley is given as:

$C = 2D_1 + D_2$ (10)

H. Design for Speed Ratio for V-Belt

Velocity ratio for the V-belt is the ratio between the velocity of the driver and the driven. It may be expressed mathematically as:

$\frac{N_2}{N_1} = \frac{D_1}{D_2}$ (11)

I. Determination of Lap Angle

The equation used for the calculation of lap angle is expressed as follow:

$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$(Khurmi and Gupta, 2013) (12)

However, for open belt angle of lap, Equation (13) is used;

$\alpha = 180 - 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$ (13)

J. Determination of Torque

The torque is given by Equation (14):

$T = Fl$ (14)

K. Determination of Power

The power requires to decorticate the groundnut is the power that turns the shaft and is calculated as follow:

$P = FV$ (15)

But;

$V = \frac{\pi DN}{60}$ (16)

Equation (15) becomes:

$P = F\frac{\pi DN}{60}$ (17)

L. Determination of Belt Tension

The belt tension is given by Equation (18);

$2.3log\left(\frac{T_1}{T_2}\right) = \mu\alpha$ (Khurmi and Gupta, 2013) (18)

Also;

$P = (T_1 - T_2)V$ (19)

M. Shaft and Bearing Design

Fig. 1 shows the free body diagram of shaft and bearing arrangement.

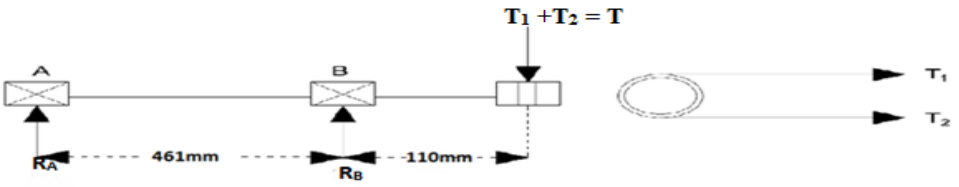


Fig.1 Free Body Diagram of Shaft and Bearing Arrangement

$R_A + R_B = T$ (20)

Upward reaction (forces) = Downward reaction (forces)

$L_{10} = \frac{60 \times L_f \times N}{10^6}$ (21)

Also;

$F_e = (XC_r\mathrm{F_r} + \mathrm{C_t F_t})\mathrm{S_f}$ (22)

If,

x=1 (inner raceway)

F_t=0 (bearing not carrying axial load)

Then,

Equation (22) reduces to;

$F_e = (XC_r\mathrm{F_r})\mathrm{S_f}$ (23)

$S_f = 1.1 \leq S_f \leq 1.5$ (24)

Equation (24) is used for determination of safety factor for rotating part.

Also;

$\frac{f_t}{XF_r} \leq Q$ (25)

C_r = 1 and C_t = 0

However if;

$\frac{f_t}{XF_r} > Q$ (26)

C_r=0.56

C_t, is either interpolated or extrapolated

The basic dynamic load is calculated from the Equation (27);

$C = L_{10}^{\frac{1}{K}} Fe$ (27)

DESCRIPTION AND OPERATING OF THE MACHINE

The feed hopper is trapezoidal in shape and was constructed from mild steel material. It has two openings (i.e., large upper and lower opening). The larger upper opening was used for feeding of roasted groundnut seeds into the decorticating chamber while the smaller lower opening connects the hopper to the decorticating chamber where collection of successfully decorticated groundnut seeds took place. The frame of the machine is made with mild steel square angle bar of thickness 4 mm. The fabrication procedure consisted of cube frame measuring 792mm x 505mm x 498mm.

The major components of the machine are as follows: feed hopper, bearing, collection/product exist tray, pulley, machine top plate, V-belt, electric motor, support frame, cloth conveyor, rollers, rectangular mild steel plate embedded with foam, bearing and shaft. The decorticating operation is based on the traditional method of using hand to rub the ground. In this case, the machine is power by an electric motor. A rectangular mild steel plate embedded with foam rollers is rubbed against each other and the groundnut seeds thereby producing the required friction. The groundnut seeds come in contact with the two members (i.e., rectangular plate material produced from mild steel material that is embedded with foam underneath it). Also, there is a cloth conveyor material that moves with the help of shaft roller driven by the electric motor and a stationary member, comprising the plate and foam. When the groundnut comes in contact with these two members, decorticating took place as a result of friction. Fig. 2 shows the isometric modeled view of the machine and Fig. 3 shows the isometric skeletal view of the machine. Fig. 4 shows the exploded view of the machine.

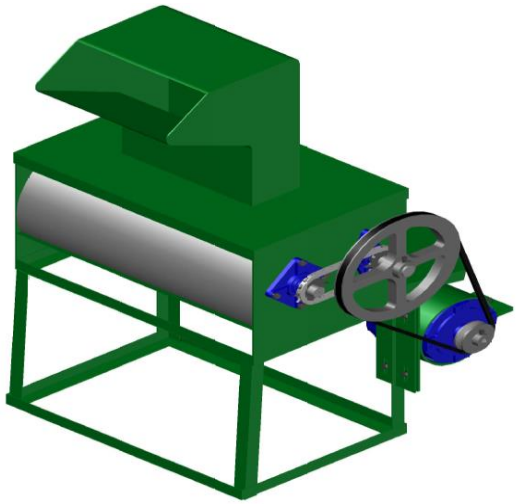
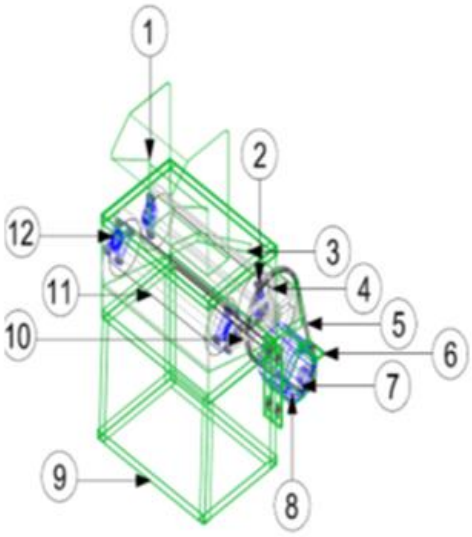
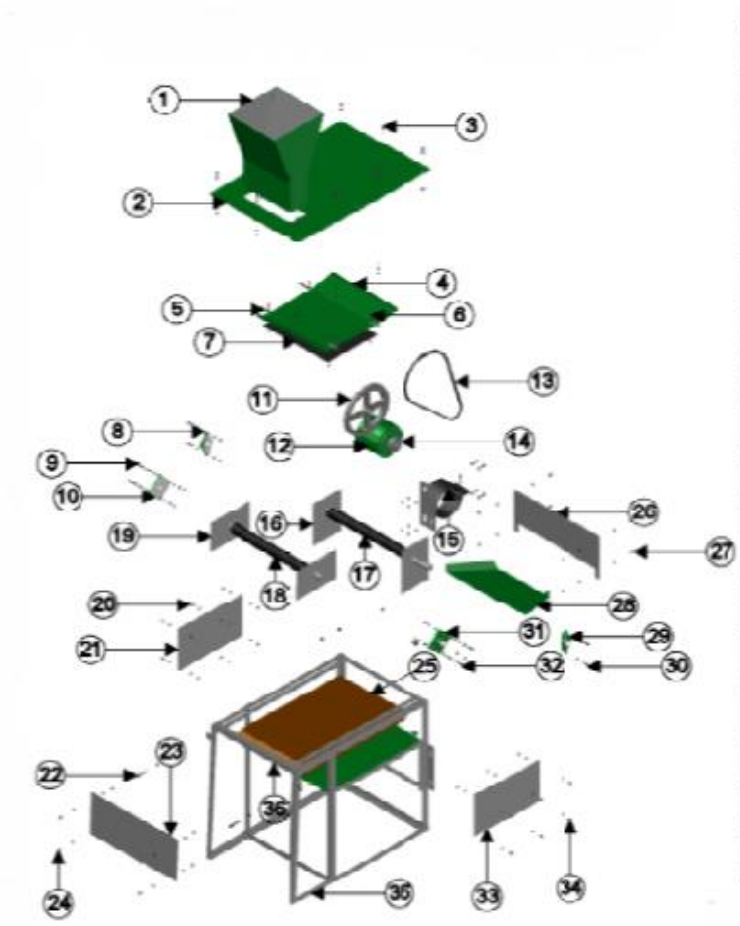


Fig.2: Isometric Modeled View of Groundnut Decorticating Machine



S/N	Description
1	Feed Hopper
2	Bearing
3	Collection/ product exit tray
4	Pulley
5	Drive belt
6	Electric motor support frame
7	Electric motor pulley
8	Electric motor
9	Machine frame
10	Belt and pulley
11	Rectangular plate embedded with foam
12	Bearing

Fig.3: Isometric skeletal View of Groundnut Decorticating Machine



S/NO.	DESCRIPTION	QTY.
1.	FEED HOPPER	1
2.	MACHINE TOP COVER PLATE	2
3.	TOP COVER PLATE BOLT AND NUT	10
4.	TOP SUPPORT PLATE	1
5.	PLATE HOLDER	4
6.	PLATE HOLDER BOLT AND NUT	8
7.	FOAM	1
8.	PILLOW BLOCK BEARING (LEFT SIDE)	1
9.	FLANGE BEARING BOLT AND NUT	4
10.	FLANGE BEARING (LEFT SIDE)	1
11.	DRIVE SHAFT PULLEY	1
12.	ELECTRIC MOTOR	1
13.	DRIVE BELT	1
14.	ELECTRIC MOTOR PULLEY	1
15.	ELECTRIC MOTOR SUPPORT	1
16.	PILLOW BEARING SUPPORT PLATE	2
17.	DRIVE SHAFT	1
18.	DRIVEN SHAFT	1
19.	FLANGE BEARING SUPPORT PLATE	2
20.	LEFT SIDE COVER PLATE BOLT & NUT	6
21.	LEFT SIDE COVER PLATE	1
22.	ADJUSTER BOLT AND NUT	2
23.	FRONT PLATE COVER	1
24.	FRONT COVER PLATE BOLT AND NUT	4
25.	CLOTH MATERIAL	1
26.	BACKCOVER PLATE	1
27.	BACKCOVER PLATE BOLT AND NUT	4
28.	COLLECTION TRAY	1
29.	PILLOW BLOCK BEARING (RIGHT SIDE)	1
30.	PILLOW BLOCK BEARING BOLT & NUT	2
31.	FLANGE BEARING (RIGHT SIDE)	1
32.	FLANGE BEARING BOLT & NUT	4
33.	RIGHT SIDE COVER PLATE	1
34.	COVER PLATE BOLT & NUT	6
35.	MACHINE FRAME	1
36.	FRAME BASE PLATE	1

Fig.4: Exploded View of Groundnut Decorticating Machine

RESULTS AND DISCUSSION

Table 1 shows the results obtained from detailed design of the groundnut decorticating machine. The analysis of results obtained from detailed design of the machine reveal that the volume of feed hopper was 0.0421m^3. The volume of the decorticating chamber which is the difference between the volume of feed hopper, volume of foam lagging, volume of bearing housing, and volume of rectangular plate was calculated as 0.0308m^3. The belt tension, distance between driver and driven pulley, length of belt, angle of lap, torque and power required for decortication of the roasted groundnut seeds were obtained as 1071.37N, 0.400m, 1.24, 2.26rad, 83.67Nm, and 2hp respectively. The algebra sum of upward and downward reactions acting on the machine shaft were zero, and this simply means that the forces acting upward were equal to all forces acting downward on the machine shaft.

Table 1 Results of Detailed Design

S/N	Parameters	Symbol	Calculated Data
1	Volume of feed hopper	m^3	0.0421
2	Volume of foam lagging	m^3	0.00515
3	Volume of bearing housing	m^3	0.000511
4	Volume of rectangular plate	m^3	0.00566
5	Volume of decorticating chamber	m^3	0.0308
6	Density of groundnut	kg/m^3	600.00
7	Weight of groundnut	N	181.104
8	Distance between driven and driving	m	0.400
9	Length of belt	m	1.24

10	Diameter of driver pulley	m	0.05
11	Diameter of driven pulley	m	0.15
12	Angle of lap	rad	2.26
13	Torque	Nm	83.67
14	Power	hp	2.00
15	Factor of safety	-	1.4
16	Belt tension	N	1071.37 (Acting downward)
17	Reaction at bearing A	N	255.64 (Acting downward)
18	Reaction At bearing B	N	1327.01 (Acting upward)
19	Basic dynamic life of bearing	milli.rev.	1900.08
20	Basic dynamic load of bearing A	N	3167.38
21	Basic dynamic load of bearing A	N	16,441.65

Ten consecutive masses of roasted groundnut seeds were used to evaluate the designed machine for performance. The time required for complete decortication of roasted groundnut seeds was recorded and this was used to determine the machine throughput capacity. The mass of roasted groundnut seeds and mass of completely decorticated groundnut seeds were used to calculate the machine efficiency. Table 2 shows the results of performance test and evaluation. The machine throughput capacity is given Equation (28).

$$MTC = \frac{M}{T} \tag{28}$$

The efficiency of the machine is given by Equation (29),

$$Efficiency = \frac{M_{DG}}{M_{RG}} \tag{29}$$

The average efficiency, average mass of roasted groundnut seeds and decorticated groundnut seeds, average decorticating time were calculated using Equation (30).

$$Average = \frac{\Sigma M}{n} = \frac{\sum T}{n} = \frac{\sum MTC}{n} \tag{30}$$

Table 2 Results of Performance Test and Evaluation

S/N	$M_{(RG)}$ (kg)	$M_{(DG)}$ (kg)	T_D(sec.)	MTC (kg/sec)	Efficiency (%)
1	10.02	8.45	85.25	0.1175	84.33
2	11.25	9.35	95.24	0.1181	83.11
3	12.05	10.01	105.05	0.1147	83.07
4	13.55	11.12	118.02	0.1148	83.30
5	15.45	13.27	121.15	0.1275	85.89
6	16.25	14.01	129.09	0.1259	86.22
7	16.85	14.04	131.25	0.1284	83.32
8	17.35	14.91	145.09	0.1196	85.94
9	17.95	15.08	147.65	0.1175	84.01
10	18.00	15.33	150.18	0.1199	85.17
Σ	148.72	125.57	1227.97	1.2039	844.36
Ave.	14.872	12.557	122.797	0.1204	84.44

Fig. 5 shows the plot of performance test evaluation using mass of roasted groundnut seeds, mass of useful decorticated roasted groundnut seeds, decorticating time, and machine throughput capacity. The results of the ten consecutive test obtained reveal that the machine efficiency ranges from 83.07% to 86.22%. Moreover, as the mass of roasted groundnut seeds increases, the time required to decorticate the roasted groundnut seeds increases also. It was observed, that the quantities of useful groundnut seeds decorticated without damaging the seeds was reasonable.

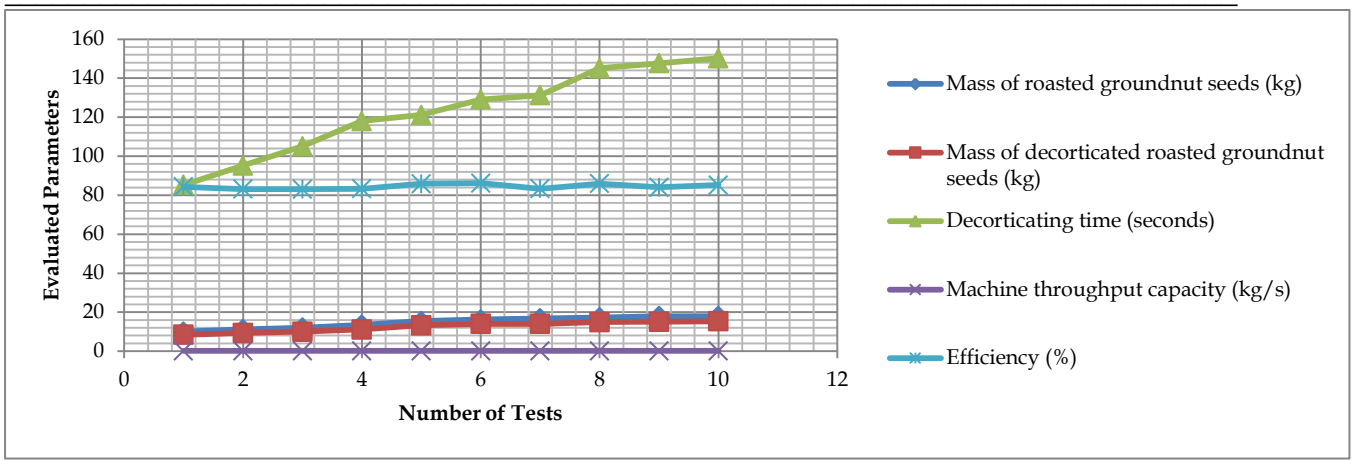


Fig.5 Graph Performance Test and Evaluation

Fig. 6 shows the average values of efficiency, average mass of roasted groundnut seeds, and average mass of useful decorticated groundnut seeds, average decorticating time, and average machine throughput capacity. The outcome of the results obtained show that an average efficiency of 84.44%, average machine throughput capacity of 0.1204kg/s, average decorticating time of 122.797seconds, average mass of useful decorticated groundnut seeds of 12.557kg, and average mass of groundnut seeds of 14.872kg were obtained.

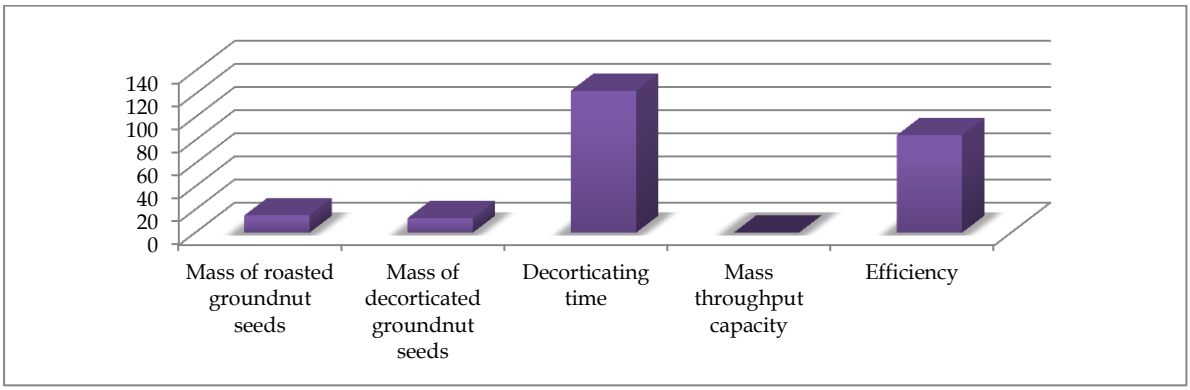


Fig.6 Summary of Average Successive Ten Tests

CONCLUSION

In this research work, performance evaluation of an improved roasted groundnut seeds decorticating machine designed to solve the problem of long age traditional method of decorticating roasted groundnut seeds in Nigeria was carried out. A minimal time of decorticating useful roasted groundnut seeds were achieved. Besides, an average efficiency of 84.44% was obtained. Thus, the machine performance is satisfactory, and can be used to replace the traditional/manual method of decorticating roasted groundnut seeds in developing countries.

CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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