DEVELOPMENT AND PERFORMANCE EVALUATION OF A PALMYRA PALM SEED CRACKING MACHINE

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ABSTRACT

The most common method of seed cracking which is still widely used in the some parts of Nigeria is by manually breaking the seed one at a time between the palms or using hard objects which is tedious, time consuming and ineffective. In view of the difficulties associated with palmyra palm seed processing, a machine for cracking palmyra palm nut was developed and tested taking into cognisance the engineering properties of the palmyra palm seed. The machine was evaluated using the seeds at three different moisture content levels of 8.09, 7.04 and 5.50 % and machine speeds of 1100, 1200, and 1480 rpm respectively. The test was replicated thrice. Also a model regression equation was also developed to help predict the optimum performance of the machine. The machine had average cracking efficiency of 64.00, 80.00 and 88.00 % at speed of 1100, 1200 and 1480 rpm respectively. However, the highest cracking efficiency of 88.00 % and lowest kernel breaking ratio of 5.50 were observed at speed of 1480 rpm and moisture content of 5.50 %. Analysis of variance results indicate that, the interaction between the speeds and moisture content has significant effect on the cracking efficiency ($P \leq 0.005$). The developed machine has a through put capacity 160 kg per day as against the hand cracker of 4 kg per day, which means that the machine could reduce drudgery, save time and encourage Palmyra palm seeds farmers to go into mass production.

Key words: *Palmyra palm seed, cracking clearance, cracking efficiency, kernel breaking ratio*

INTRODUCTION

Palmyra palm tree *(Borassus aethiopum)* grows in the tropical or sub-tropical climates. Palmyra palm consist of genus of six species of palms that grow in great abundance on fluvial flats and coastal plains, and also occurs in open secondary forest, dense forest borders and in savannah areas where it is restricted to grassland with annual rainfall of 500-1000 mm and high ground water table. It is irregular, widely distributed, typically found at altitudes of up to 400 m, but up to 1200 m in Africa and Asia. Growth of the Palmyra palms depends very much on soil conditions. Palmyra palm tree grows best in sandy and well - drained soil but prefers alluvial soils near watercourses. Prefers PH in the range 5.5- 7. Established plants are draught tolerant (Arbonnier, 2004).

The growth of Palmyra trees have been categorized into three phases. The first phase involves leaf development, the second phase involves rapid growth of the trunk above the ground and takes place from the 8 to 20 year of age. The third phase involves flowering and shedding of leafstalks (Poinar, 2002; Arnold and Mohsenin, 1971). The palmyra tree has slow growing ability and very long life, to over one hundred years (Arbonnier, 2004). A picture of the palmyra palm tree is shown in Plate I.

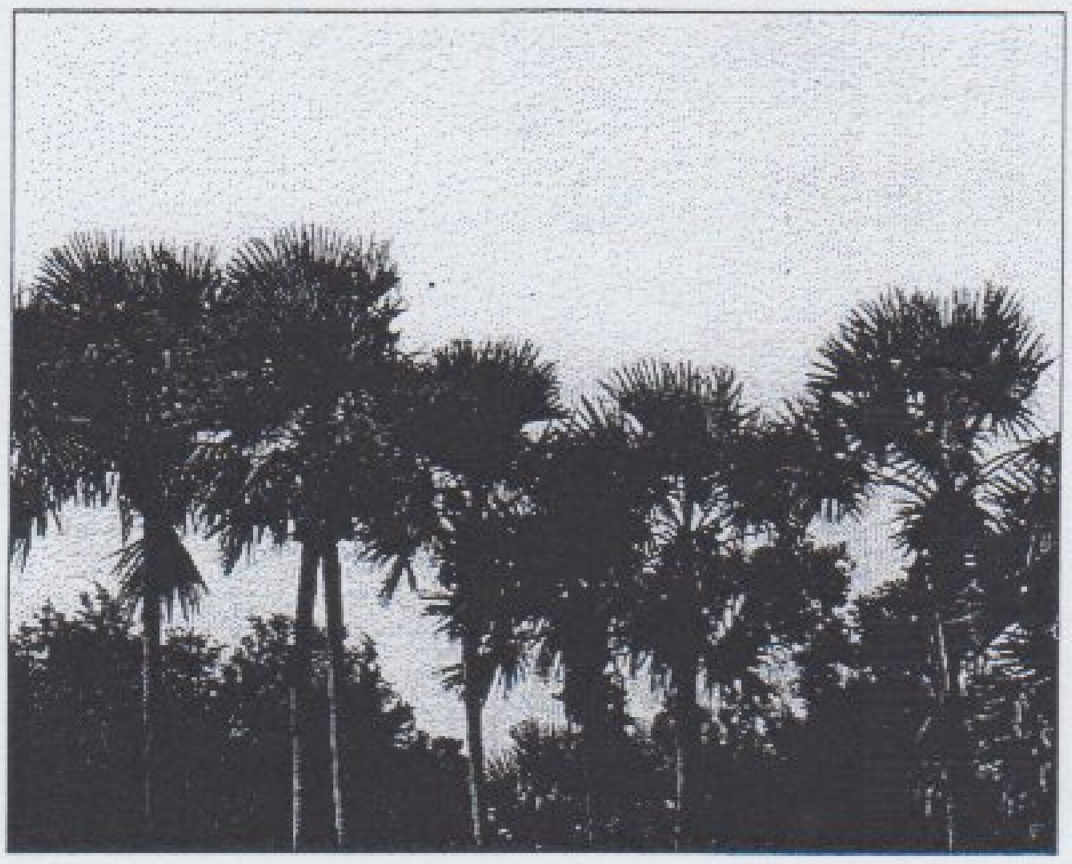

Plate I. Palmyra palm *(Borassus Aethiopum)* trees

Palmyra palm is common in populated areas where most of its products are used for domestic and industrial raw materials. Almost all its parts are useful in food production, such as: oils, timber, dyes, fibers, wine, and raw materials. The wood of the Palmyra palm tree have high resistant to termites and fungi, and is good in constructions and also for household furniture. The roots is used to treat stomach parasites, bronchitis, asthma sore throats and mouthwash. The leaves are used for thatching, mat, basket, fan, hat, umbrellas and writing materials. The seedlings, fruits are eaten as a food supplement and both the fruit pulp and seeds are edible. The fruit is made into soft drinks (Ogbuagu *et al.,* 2013). The fruits, seeds and kernels of Palmyra palm are shown in plate II (A, B and C).

(A) (B) (C)

Plate II. Palmyra palm parts: (A) Fruits, (B) Seeds and (C) Palmyra kernels

The fruit measures about 15.25 cm in diameter, has a black husk, and is borne in clusters. The small fruit are pickled in vinegar while the shell of the fruit can be punctured with a finger and the sweetish liquid sucked out for refreshment like coconut water. The top portion of the fruit must be cut off to reveal the three sweet jelly seeds socket, translucent pale-white. The jelly part of the fruit is covered with a thin, yellowish-brown skin (Sakande *et al.,* 2004). The ripened fibrous outer layer of the palm fruit can also be eaten raw, boiled, or roasted. People have perfected the art of making various sweet dishes with the yellowish viscous fluid substance obtained from a ripe palm fruit. The pulp of mature fruit is reportedly rich in vitamins A and C (Ogbuagu *et al.,* 2013).
The peeled seedling are eaten fresh or sun-dried, raw or cooked in various ways. They also yield starch. It has been proposed for commercial starch production. The top portion of the young fruit has three seeds inside, sometimes two but rarely one, in which the jelly-like seed is found. The jelly like is a famous and delicious summer food (Awal *et al.,* 1995).
Over the years the cracking of Palmyra palm seed to release the kernel is normally done manually which is tedious and time consuming. The minimum force and pressure required to break the seed is about 7.45 kN and 1.46 kN/mm^2 respectively (Eric *et al.,* 2009). Despite the numerous uses of Palmyra palm there is no machine for cracking the seeds. In view of the difficulties associated with processing of palmyra palm seed, a machine for cracking palmyra palm seed become imperative.

MATERIALS AND METHODS

Materials

The materials used were selected based on their availability, cost, suitability and viability in service among other considerations. In the design of this palmyra palm seed cracking machine some properties of palmyra palm seed were considered such as physical properties (shape, size, sphericity, surface area and weight of the palmyra palm seed), mechanical properties (compressive strength of palmyra palm seed when placed on horizontal and vertical) and hardness of the palmyra palm seed were determined as outlined by (Balami *et al.*, 2014).

Methods

Determination of Moisture Content of Palmyra Palm Seed

The moisture content of Palmyra palm seeds was determined by drying the sample in an Air circulating oven (PBS118SF, England) at 105 °C for 24 hours on wet basis. The drying condition was decided based on preliminary studies and in reference to (ASAE, 2001; Carman, 1996). In order to achieve the desired moisture level for the study, Palmyra seeds in three separate polyethylene bags were conditioned by adding a measured amount of water based on the equation (1).Each test was replicated 3 times and the mean values of moisture content were obtained.

$$Q = W_i \frac{m_f - m_i}{100 - m_f} \quad (1)$$

Where:
Q = mass of water to be added in (g),
W_I = initial mass of the sample in (g),
m_i = initial moisture content of the Palmyra palm seeds in (%) and
m_f = final moisture content, (%).

Determination of the Volume of hopper

The volume of the hopper is similar to that of trapezium and therefore determined using equation 2.

$$V = \frac{1}{2} hl(a_1 + a_2) \quad (2)$$

Where:
a_1 = length of the bottom of the hopper
a_2 = length of the top part of hopper
h = height of the hopper.
l = Length of the hopper

Pulley Diameter

The ratio of the pulley for the electric motor to that of the cracking shaft was calculated as given in equation 3 (Spott 1988).

$$N_1 d_1 = N_2 d_2 \quad (3)$$

Where: N_1 = Speed of the driving pulley, rpm; N_2 = Speed of the cleaning shaft, rpm; d_1 = Diameter of the driving pulley, mm; d_2 = Diameter of the driven pulley, mm

Tensions on belts

The tensions on the belt were determined using Equations 4 and 5 as given by Khurmi and Gupta (2007).

$$\frac{T_1}{T_2} = e^{\mu\theta_1} \quad (4)$$

$$P = (T_1 - T_2)V \quad (5)$$

Where: T_1 = tension of belt on tight side in (N); T_2 = tension of belt on slack side (N); μ = mean coefficient of friction of palmyra palm seed; θ_1 = angle of contact between motor pulley and belt in radian; v = velocity of belt m/s; P = power from electric motor.

Belt Length

The belt length was determined using equation 6 (Khurmi and Gupta 2007).

$$L = \frac{\pi}{2}(d_1 - d_2) + 2C + \left(\frac{d_1 - d_2}{4C}\right)^2 \qquad (6)$$

Where: $C = 2d_1$ = centre distance in (m);
d_1, d_2 = diameters of electric motor and blower pulley, mm.

Angle of wrap

The angle of wrap between the belt and electric motor pulley was determined using equation 7 and 8.

$$\theta_1 = 180 - \sin^{-1}\frac{d_1 - d_2}{2C} \qquad (7)$$

$$\theta_2 = 180 + \sin^{-1}\frac{d_1 - d_2}{2C} \qquad (8)$$

Where:
θ_1 = angle of wrap between belt and motor pulley (degree), θ_2 = angle of wrap between belt and machine pulley (degree), C = centre distance between pulley, m

The approximate length of a belt

The length of the belt was determined using equation 9as expressed by Khurmi and Gupta, (2012).

$$L = 2C + \frac{1.57(D_1 + D_2)}{2} + \frac{(D_1 + D_2)^2}{4C} \qquad (9)$$

Where:
L = the length of the belt,
From standard table, a belt designated as A50 was selected based on the power rating of the prime mover, the length of belt, the centre distance and the correction factor for belt and angle of wrap

Determination of force required to crack the palmyra palm seed

The force required to crack the palmyra palm seed is as given in equation 9 by Rajput (2012):

$$F = \frac{T}{r} \qquad (10)$$

Where:
F = the force required to break the seed in N
T = the torque in Nm
r = the radius of the cracking mechanism shaft in m

Determination of Total Power Required by the Machine

The total power (P_T) required to operate the cracking machine was determined using equation 11as reported by Khurmi and Gupta (2006).

$$P_T = P_s + P_C \qquad (11)$$

Where:
P_S – Power to crack the seed, watt
P_C– Power to operate the cracking mechanism, watt
But:

$$P_S = T\omega;\ T = Fr;\ F = Mg$$

$$P_C = Fr\omega$$

But:

$T = Fr$
$F = Mg$
Where:
$T = Torque$, Nm
F = force required to crack the seed, N
M = Ms + Mb + Mp - masses of seeds, beaters and pulleys.
r = radius of the cracking mechanism, mm
ω = angular velocity, rad/sec
g – acceleration due to gravity, m/s^2

Determination of mass of the Beaters
The mass of the beaters was determined using equation 12.
Mass of beaters (M_B) = $\delta_b(NLBT)$ (12)
Where:
M_B = Mass of the beaters (kg)
δ_B = Density of the beaters (kg/m^3)
N - Number of the beaters
L - Length of the beaters (m)
B - Breadth of the beaters (m)
T - Thickness of the beaters (m)

Determination of the cracking shaft diameter
The diameter of the cracking mechanism shaft was determined using the expression given in equation 13 (Rajput, 2012):

$$d^3 = \frac{16}{\pi Ss}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (13)$$

Where:
M_t = torsional force, *Nm*
M_b = bending moment, *Nm*
K_b = combine shock and fatigue factor applied to bending moment.
K_t = combine shock and fatigue factor applied to torsional moment.
Ss (allowable) for shaft with keyway is 40MN/m^2 (Khurmi and Gupta, 2012).

Design of the Cracking Unit Clearance
The clearance of the cracking unit is one of most important aspect in the design of a cracking machine and this was determined as reported by Onyechi *et al.* (2014) using equation 14:

$$\text{Cracking Unit Clearance} = \frac{a+b}{2} \quad (14)$$

Where:
a = The major diameter of the seed (mm)
b = The minor diameter of the seed (mm)

Technical Characteristics
The technical characteristics of the cracking machine is shown in Table 1.

Machine Description and Principle of Operation
The Palmyra palm seed cracking machine (Figure 1) consists of the following component: hopper with cover, cracking chamber, shaft, cracking mechanism, discharge outlet, frame, adjustable plate and prime mover. The hopper is made from 5 mm gauge mild steel sheet formed into a pyramidal frustum with a top opening of 330 mm x 330 mm and a bottom opening of 250 mm x 330 mm with sides inclined at 60 degree to help the free flow of the Palmyra palm seeds into the cracking chamber. The adjustable plate is meant for controlling the amount of seeds entering into the cracking chamber which consists of a decagonal housing made from 10 mm gauge mild steel plate. There is also a horizontal shaft made from 23 mm mild steel rod attached with 2 beaters made of 15 mm diameter mild steel circular rod arranged at intervals of 180 degrees adjacent to one another. The decagonal housing is 250 mm diameter with an opening of 250 mm x 330 mm at the upper curvature where the seeds are introduced from the hopper while the lower curvature has an opening of 50 mm where the cracked seeds escape into the discharge outlet. The machine is powered by 15 hp electric motor. The frame is made from 80 mm x 80 mm mild steel angle iron to carry and support the machine components.

Operation: As the Palmyra palm seeds are introduced into the machine through the hopper, the seeds are cracked as a result of the impact caused by the fast rotating beaters against the concave. The kernels and the cracked particles are then discharge through the discharge outlet.

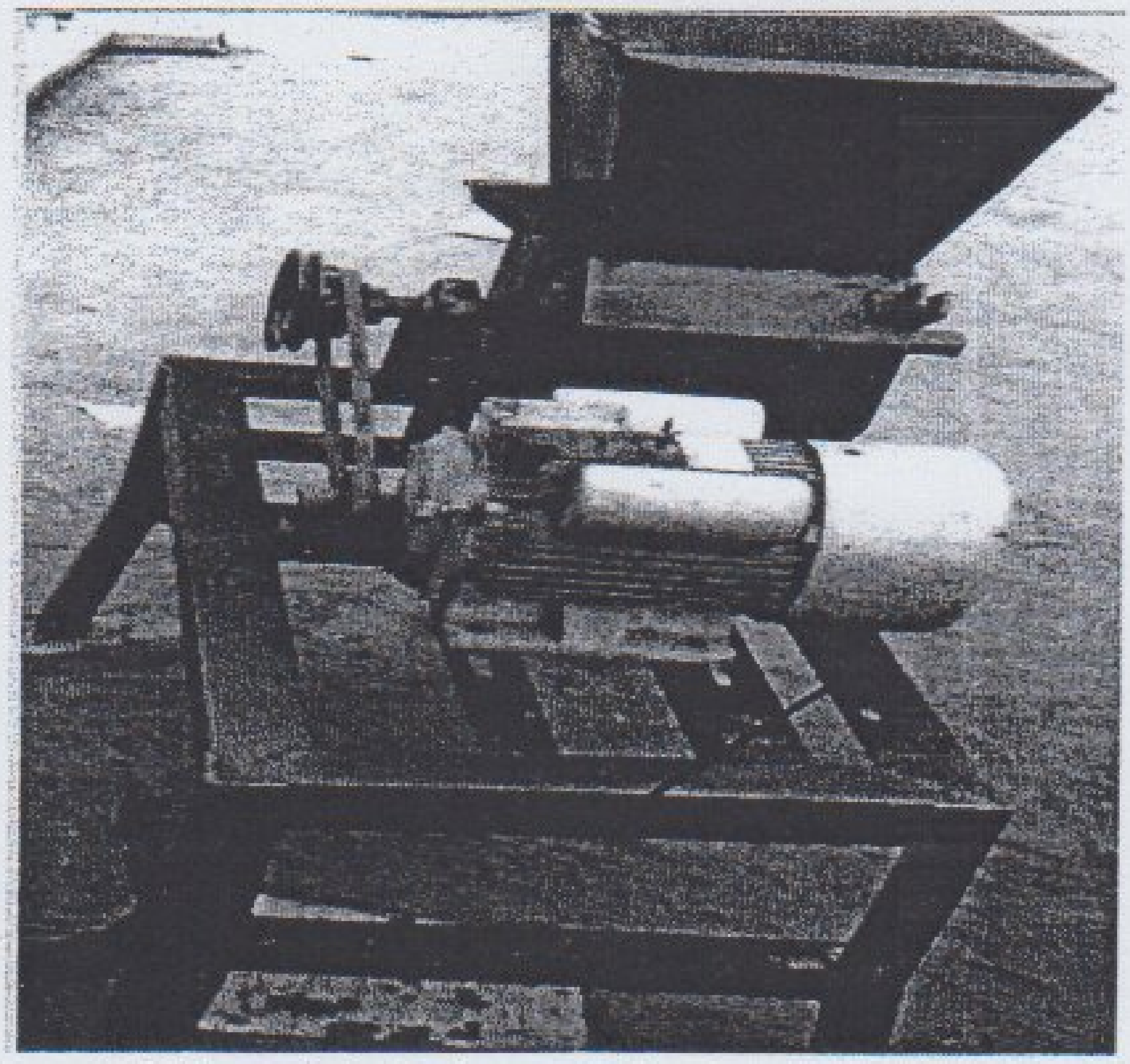

Figure 1.Pictorial View of the Palmyra Palm Seed Cracking Machine

Experimental Design

A two-variable (moisture content and speed) factorial design provides the framework for the experiments. The data obtained from the design matrix were fitted into regression equation to give the required model equation.

$$y_c = x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_{12} + \beta_4 x_1^2 + \beta_5 x_2^2 + \epsilon \quad (15)$$

y_c = Cracking efficiency

Where: $\beta_1,\ \beta_2,\ \beta_3,\ \beta_4\ and\ \beta_5$- the regression coefficient estimates

ϵ - the experimental error.

x_o – dummy variable; x_1 – moisture content; x_2 – cracking speed; $x_1 x_2$ – interactions

The experiment was carried out based on two factors and three levels of speed (1100, 1200, 1480 rpm) and moisture content (8.09, 7.04 and 5.50 %) and replicated thrice

Performance Evaluation

After obtaining some fresh Palmyra palm fruits from Wushishi main market, Niger state, Nigeria, the fruits were sorted out and cleaned before removing the cap to get to the seed. After cleaning the seeds and the fibre threads removed, 60 kg of the seeds at an average moisture of 6.88 % were divided into (10, 20, 30 kg) and fed into the machine for cracking at three machine speeds of (1100, 1200, 1480 rpm). The weight of the kernels collected at the ends of each run were recorded and the cracking efficiency, percentage cracked kernel, percentage of uncracked kernels and kernel breaking ratio were determined using the equations 15 – 18. The experiment was replicated thrice

Cracking Efficiency

The Cracking efficiency ($\mathcal{E}_c$) was determined using equation 16.

$$\text{Cracking efficiency } (\mathcal{E}_c) = \frac{C_{udk}}{T_{fs}} X\ 100\ \% \quad (16)$$

Where:

C_{udk} = Total mass of cracked seeds recovered

T_{sf} = Total mass of the seeds fed into the machine

Percentage cracked kernel ($\mathcal{E}_{bk}$)

The percentage cracked kernel was determined using equation 17.

$$\varepsilon_{ck} = (100 - total\ \%\ \text{of cracked kernel}) \quad (17)$$

Percentage of uncracked Seeds

The percentage uncracked seeds was determined using equation 18.

$$\varepsilon_{uck} = (\frac{T_{us}}{T_{fs}})100\ (\%) \quad (18)$$

Where:
T_{us} = total mass of uncracked kernels,
T_{sf} = total mass of fed into the machine

Kernel Breaking Ratio (KBR)
The Kernel breaking ratio was determined using equation 19.

$$\text{Kernel Breaking Ratio (KBR)} = \frac{C_{dk}}{C_{dk} + C_{udk}}\ X\ 100\ \% \quad (19)$$

Where:
C_{dk} = Mass of broken kernels recovered
C_{udk} = $Mass\ of$ unbroken kernels recovered

RESULTS AND DISCUSSION

The results of the physical and mechanical properties of the palmyra palm seed used in the design of the cracking machine (Balami *et al.*, 2015) are present in Tables 1 – 3. Table 4 presents the technical characteristics of the developed machine while Table 5 presents effect of machine speed and moisture content on the cracking machine performance. At 5.5 % moisture content and operating the machine at speeds of 1100, 1200 and 1480 rpm, cracking efficiencies of 64.00, 80.00 and 88.00 % were obtained. This agreed with the work reported by Ologunagba *et al.* (2010) and Ologunagba (2012). The results also showed that the cracking efficiency increased with decrease in moisture content at constant shaft speed. At a speed of 1480 rpm, the efficiencies were 81.30, 86.67 and 88.00 % for moisture contents of 8.09, 7.04 and 5.50 % respectively. Hence, test results revealed that the optimum performance of the machine was at moisture content of 5.50 % of Palmyra palm seed and 1480 rpm machine shaft speed. The model has a P-value of 0.0202 which is highly significant indicating that both the moisture content and speed are responsible for the cracking efficiency. The interaction between the two factors speed and moisture content has significant effect on the cracking efficiency at ($P \leq 0.05$). The response surface plot (Figure 2) presents the simulated data. The model data predicted follows the pattern of the real data of the experimental data, which shows a good correlation between them. The significant of each term in the model was determined by calculating the t- statistic value and comparing it with the table t- statistic value (t_{cal}> t [α, N(r-1)]) at significant of 5 % significance level. Comparing each of the calculated t-statistic ($t_{(0.005,18)}$ = 1.734), the regression coefficient of $x_1$is insignificant on the cracking efficiency. It was also observed from the model equation that the speed as a singular variable (x_2) has a positive effect on the cracking efficiency. It therefore means that the higher the speed of the cracker the better the cracking efficiency.

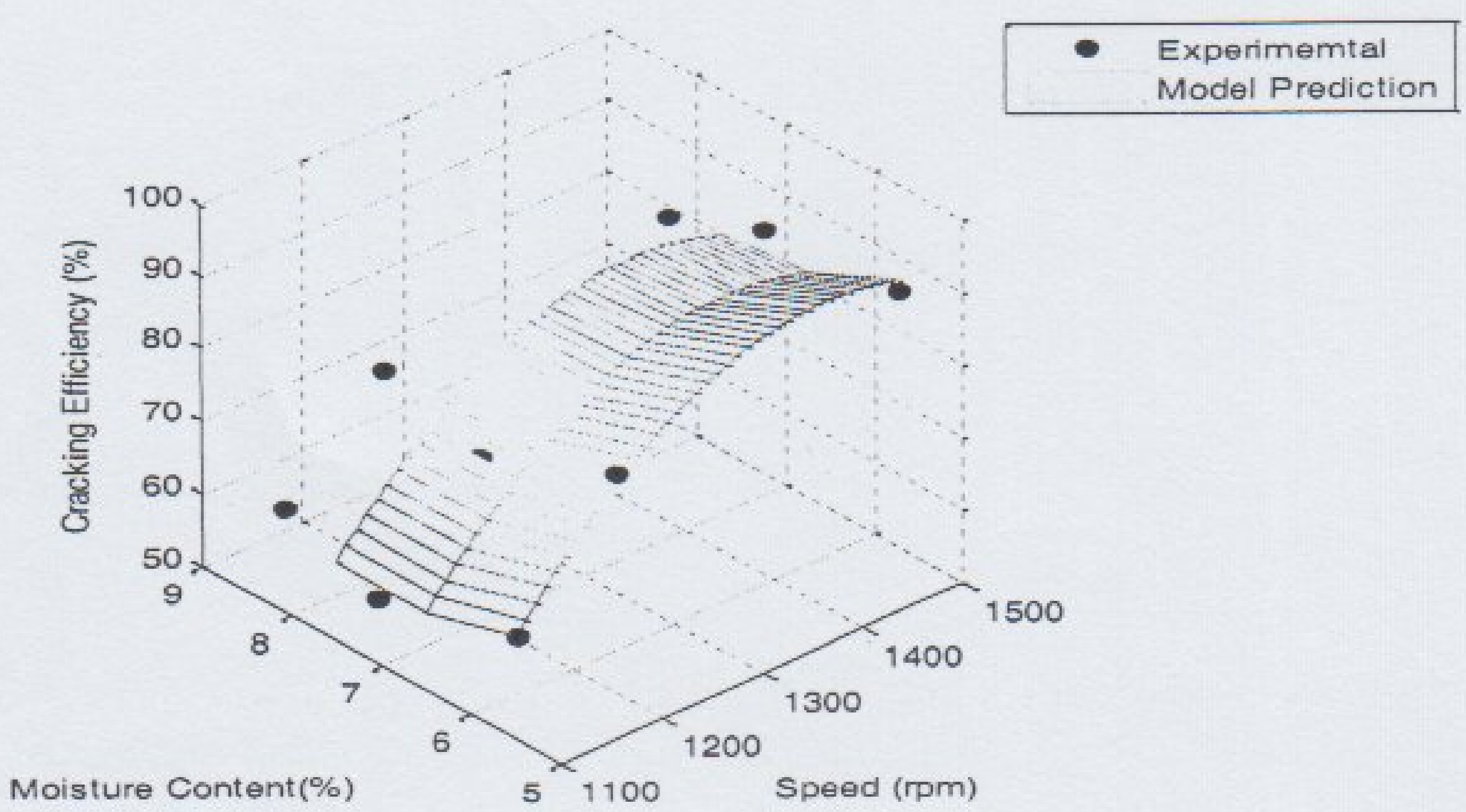

Figure 2: Response Surface Plot for the Cracking Efficiency

CONCLUSIONS

A machine for cracking palmyra palm seed was successfully developed and tested. At machine speed of 1100, 1200 and 1480 rpm and an average moisture content of 5.50 % the machine has cracking efficiency of 64.00, 80.00 and 88.00 %. The kernel breaking ratio decreases with increase in machine speed while uncracked seed percentage decreases as the machine speed increases. The developed machine has a through put capacity 160 kg per day as against the hand cracker of 4 kg per day, which is believed will surely reduce drudgery save time. The interaction between the two factors has significant effect on the cracking efficiency at $P \leq 0.05$.

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Table 1: Technical Characteristics

Designed Parameters	Calculated Values
Shaft Diameter	23 mm
Clearance gap	7.32 cm
Total Power Required (P_T)	15 hp
Mass of the Cracking mechanism(M_D)	8.00 kg
Mass of the pulley	6.78 kg
Total torque (τ_T)	15.64 Nm
Maximum Bending Moment (M_{max})	24.28 Nm
Overall length	980 mm
Overall height	470 mm
Overall width	1130 mm

TABLE 2: Physical Properties of Palmyra Palm Seed at 3 moisture content levels

Parameter	Moisture content (%wet basis)			
	N	5.50	7.04	8.09
Major Diameter (cm)	20	7.75±0.73	8.65±0.69	10.89±1.66
Intermediate Diameter (cm)	20	7.22±0.79	8.00±0.80	7.76±1.93
Minor Diameter (cm)	20	6.88±0.66	7.77±0.77	9.14±1.84
Geo. Mean Diameter (cm)	20	7.25±0.67	8.16±5.04	9.11±1.53
Surface Area (cm^2)	20	167±30.30	209±79.80	270±95.90
Bulk density (c/cm^2)	20	0.35±0.11	0.24±0.06	0.33±0.14
True density (g/cm^3)	20	0.94±0.13	0.91±0.13	1.55±0.37
Porosity (%)	20	62.32±13.76	73.16±7.42	78.31±8.54
Sphericity (%)	20	0.94±0.04	0.94±0.07	0.85±0.11
Volume (cm^3)	20	134.30±16.9	137.75±16.92	141±20.08
Arithmetic mean diameter (cm)	20	7.28±0.67	8.17±0.59	9.25±1.51

N = Number of sample, Values with ± = standard deviation

Table 3: Coefficients of Friction of Palmyra Palm Seed and its Kernel at 8.09 % M.C

Properties	Mean of Seed	Max. seed	Min. seed	Mean of kernel	Max. kernel	Min. kernel
Plywood	0.36 ±0.06	0.44	0.23	0.44 ±0.03	0.51	0.38
Glass	0.25 ±0.02	0.29	0.22	0.31 ±0.03	0.36	0.26
Metal	0.34 ±0.05	0.39	0.26	0.36 ±0.04	0.43	0.26

Table 4: Mean Values of Mechanical properties of Palmyra palm seed

Parameter	Moisture content (% wb)		
	5.50	7.04	8.09
F at peak (KN)	6.29±0.49	6.67±0.48	8.03±1.87
δ at peak (KN/mm	0.29±0.05	0.41±0.05	0.46±0.07
F at break (KN)	7.73±0.87	8.80±0.54	10.82±0.23
δ at break (KN/mm	1.16±0.08	1.22±0.14	1.46±0.19
Deformation at peak (mm)	2.82 ±0.20	3.49±0.36	3.98±0.19
Deformation at break (mm)	3.93±0.17	3.61±0.35	4.10±0.16

F = Force, δ = Stress, Value of Standard Deviation

Table 5: Effect of Speed and Moisture Content on the Machine Performance Indices

Machine Performance Indices	Machine Speed								
	1100 rpm			1200 rpm			1480 rpm		
	At 8.09, % m.c	At 7.04, % m.c	At 5.50, % m.c	At 8.09, % m.c	At 7.04, % m.c	At 5.50, % m.c	At 8.09, % m.c	At 7.04, % m.c	At 5.50, % m.c
Cracking efficiency (%)	64.00	58.67	64.00	77.67	72.00	80.00	81.30	86.30	88.00
% Uncracked (%)	12.00	12,00	6.00	12.00	9.30	8,00	9.30	8.00	5.30
Kernel Breaking Ratio (KBR)	26.67	33.20	29.70	16.67	20.37	13.05	11.00	5.87	5.53