VOL. 11, NO. 3, MARCH 2016 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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DEVELOPMENT AND EVALUATION OF A JATROPHA FRUIT HUSKING MACHINE

Abdelmutalab Kheiralla[1], ElKamil Tola[1, 2], Adil Korsha[1] and Abbas Eltigani[1]
[1]Department of Agricultural Engineering, Faculty of Engineering University of Khartoum, Khartoum, Sudan
[2]Precision Agriculture Research Chair, King Saud University, Riyadh, Saudi Arabia
E-Mail: etola@ksu.edu.sa

ABSTRACT

The *Jatropha Curcus* L has emerged on the world energy race as a promising plant for the production of biodiesel. However, this crop still lacks the development of specialized machine for post-production. The objective of this research work was to design, develop and evaluate small scale Jatropha fruits husking machine for bio-fuel production. Engineering properties for Jatropha fruits before husking and after husking have been successfully studied and evaluated. The Jatropha fruit before husking had an average geometric mean diameter, sphericity, crushing force, length, width, and thickness of 21.80 ± 0.03 mm, 0.84 ± 0.06%, 79 N.m, 26.49 ± 8.07 mm, 21.088 ± 4.92 mm and 19.280 ± 4.68, respectively. While, Jatropha fruit after husking (seeds) had average length, width, and thickness of 24.49 ± 8.07 mm, 19.088 ± 4.92 mm, and 17.28 ± 4.68 mm, respectively. The developed husking machine consists of frame, feed hopper, fruit husking chamber, concave sieve, rotating blades, discharge outlet and a vibrating separator equipped with a sieve for the separation of seeds and husks. The machine was powered with a 0.5 hp AC motor, and had overall dimensions of 1250 mm length, 1100 mm height, and 500 mm width. The obtained results showed that the mean values of the cleaning efficiency, husking capacity, husks percentage and whole seeds percentage were 91.78 ± 1.97%, 44.058 ± 2.79 kg h^{-1}, 34.24 ± 0.94% and 61.99 ± 3.52%, respectively. The husking machine total cost was estimated at 600 US Dollars.

Keywords: biofuel, jatropha fruit, engineering properties, husking machine, post-harvesting.

INTRODUCTION

Introducing biofuels; which referred to any fuel obtained from organic material in solid, liquid or gaseous form (Dragone *et al*., 2010); around the world as alternatives of finite fossil fuels is of massive growth, because they are characterized as the most valuable forms of renewable and sustainable fuels. Biofuels; which are considered to be environmentally friendly and of low carbon emission compared to the traditional fossil fuels of finite availability and high impact on the environment, can play an important role in the future energy supply (Alam *et al*., 2012; Nigam and Singh, 2011; Zhuang *et al*., 2010).

As reported by HELPE (2013), production of biofuels around the world has increased five times in less than 10 years, i.e. from less than 20 billion liters/year in 2001 to over 100 billion liters/year in 2011. Hence, biofuel production strategies should take into consideration food security aspects, so that biofuels can be safely produced where it is feasible from social, economical and environmental points of view. Therefore, utilizing non-food biomass raw materials, such as Jatropha curcas; can help to achieve sustainable production of cost-effective biodiesel with less emission, through the successful use of advanced biofuels technologies (Abdelrahim *et al.*, 2013)? Biodiesel produced by the transesterification of plant oil extracted from Jatropha fruits is classified within the first generation of secondary biofuels (Nigam and Singh, 2011).

Jatropha curcas L. is a drought resistant variety which develops well under a broad range of arid and semi-arid climates, and is characterized as either small shrub or large tree of up to five meters high with a lifespan of more than 50 years (Kumar and Sharma, 2005). It belongs to the family euphorbia and its origin is Mexico and Central America; then transferred to Africa and Asia, and currently it is cultivated worldwide especially under tropical and sub-tropical conditions (Warra, 2012; Brittaine.and Lutaladio, 2010; Sotolongo *et al*., 2007). Jatropha can start producing fruits from the age of six months and attains yield stability after 1-3 years age (Pradhan *et al*., 2009a). Jatropha seeds look like castor in shape, black in colour and are 42% husk and 58% kernel (Agbogidi *et al*., 2012). Also as reported by Singh *et al*. (2008), a fresh harvested and dried Jatropha fruit comprises a weight of 35-40% shell and 60-65% seed; while, the seed contains 40-42% husk/hull and 58-60% kernels. Depending on the growing season and conditions and the availability of water and nutrients, the yield of Jatropha is ranging from 0.1 to 12.0 t ha^{-1} (Openshaw, 2000; Achten *et al*., 2008, Agbogidi *et al.,* 2012). Previous studies reported high oil content of Jatropha seed. As examples: 66.4% (Adebowale and Adedire, 2006), 50% (Raja *et al*., 2011), 37.4% of the whole seed and 46.0-48.6% of the kernel (Kandpal and Madan, 1995), and 45.03% of the kernel (Pradhan *et al.*, 2009b), 27-40% of the seeds (Agbogidi *et al*., 2012).

The processes of husking and shelling Jatropha fruits are of great importance for the process of extracting Jatropha oil in terms of both oil quantity and quality. These two processes can be performed either manually or by using specialized mechanical systems (Achten *et al*., 2008; Lim *et al*., 2014). The manual or traditional methods (using hand tools and fingers) are tedious, time consuming and labor intensive processes, in addition of causing serious harm to the fingers of the workers as well as the low output rates, which was estimated at a maximum of 50 kg of dried fruits per worker (Pradhan *et al.*, 2010; Lim *et al*., 2014). Hence, the replacement of traditional methods

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used for husking and shelling Jatropha fruits with motorized mechanical systems, is of great importance to increase the output rates of the pure kernels, in order to optimize the process Jatropha oil extraction.

Currently, the process of developing mechanical systems for separating the kernels from the husks and shells of Jatropha fruits, is receiving great attention from the researchers community with a major objective of enhancing the mass production of Jatropha oil in order to optimize the process of biodiesel production. As example, Pradhan *et al*. (2009b) developed and tested a hand-operated decorticator (husking machine) for Jatropha fruits. Their results showed that the performance of the developed machine was significantly affected by both the moisture content of the fruits and the clearance between the concave sieve and the rotating blades (concave clearance). They reported whole seeds amount of 67.94% and a machine efficiency of 90.96% can be achieved at an optimum fruit moisture content of 7.97% (d.b.) and a concave clearance of 21 mm. Also Ting *et al.* (2012) fabricated and tested Jatropha Sheller consists of a main-frame, rotary cylinder, stationary cylinder and a transmission system, with shelling capacity of up to 120 kg h-1. The performance evaluation results indicated that the fabricated Jatropha Sheller was observed to attain its optimum working conditions at Jatropha fruit moisture content of 9.5% (d.b.), clearance of 6 mm and roller speed of 750 rpm.

MATERIALS AND METHODS

Jatropha husking machine was fabricated successfully and its performance was tested in terms of husking capacity, husking efficiency, cleaning efficiency and whole seed percentage. The experimental work was carried out in three stages: (i) determination of Jatropha fruit physical properties, (ii) design and fabrication of Jatropha husking machine, and (iii) assessment of the performance of the developed Jatropha husking machine.

Determination of Jatropha fruit physical properties

The physical properties of Jatropha fruits and seeds were carried out in the lab facilities of the Faculty of Engineering, University of Blue Nile. Samples from the air dried Jatropha fruits were randomly picked and used for the determination of soil moisture content and geometrical dimensions following the standard methods described by Pradhan *et al*. (2009a).

Jatropha fruits (seeds) moisture content

$$MC = \frac{M_i - M_f}{M_f} \times 100 \quad (1)$$

Where:
MC = moisture content, % (d.b.)
M_i = initial mass of fruits (seeds) in kg (g),
M_f = final mass of fruits (seeds) dried at 105 °C for 24 hours, in kg (g).

Jatropha fruits (seeds) geometrical dimensions

The size and shape of Jatropha fruits (seeds) were determined in terms of geometric diameter (D_g) and sphericity (Ø) using the relationships described by Mohsenin (1986), Equations (2) and (3).

$$D_g = (abc)^{\frac{1}{3}} \quad (2)$$

$$\varnothing = \frac{(abc)^{\frac{1}{3}}}{a} \quad (3)$$

Where

D_g = Geometric Mean Diameter, mm
A = length, the dimension along the longest axis, mm,
B = width, the dimension along the longest axis perpendicular to “a”, mm, and
C = thickness, the dimension along the longest axis perpendicular to both “a” and “b”, mm.

Design and fabrication of Jatropha husking machine

Description of the developed Husking Machine: Jatropha fruit husking machine was designed and developed for the production of Jatropha seeds. The components of the developed machine include frame, feed hopper, fruit husking chamber, concave sieve, rotating blades, discharge outlet and a vibrating separator equipped with a sieve for the separation of seeds and husks. The machine was powered with an AC motor. The three dimensional (3D) and the detailed drawing views of the developed machine is depicted in Figure-1.

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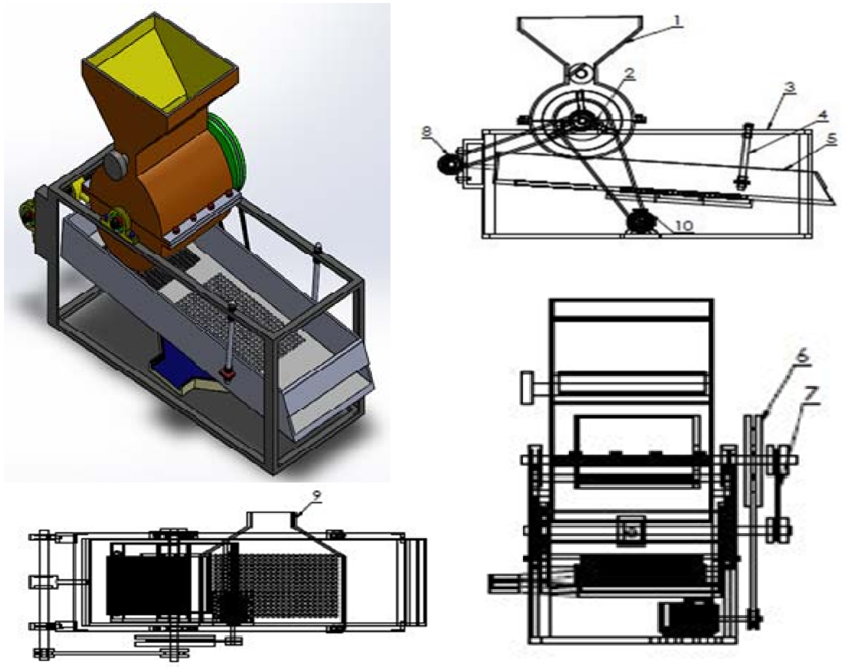

(1) Hopper, (2) Husking unit, (3) Out farm, (4) Anchor bolt, (5) Shaker,
(6) Pulley, (7) Belt, (8) Pulley cam, (9) Aquarius, (10) Motor.

Figure-1. 3D, elevation and side view of the developed Jatropha husking machine.

Design considerations for the Husking Machine: The mechanics of Jatropha fruit husking include compression, shearing and impact principles. In The developed Jatropha fruit husking machine utilized the principle of shearing force, and the factors considered in the design of the machine include: (a) materials of adequate strength and stability were used for fabrication (i.e. Mild steel and Aluminum for pulley), (b) the machine was designed for a maximum Jatropha fruits husking capacity of 80 kg h $^{-1}$; hence, the machine could be affordable for small scale farmers and micro-industries, and (c) the materials that are available locally were used in the fabrication of the components. Consideration was given to the cost of items and materials for fabrication with the ultimate aim of utilizing the cheapest available materials, yet satisfying all strength requirement

Design of husking machine components: The relevant physical and mechanical properties of Jatropha fruit and seed required as basic design data were obtained. Basic considerations were given to the design for the size/dimension and capacity of the machine, including the numbers of blades, thickness of blades and diameter of shaft. The design of the hopper is based on flow characteristics of the fruit (e.g. sphericity and angle of response). Similarly, an experiment was conducted to determine the force required to detach the seed from the fruit. A shearing force of 79 N was employed in the subsequent design and the selection of machine components such as number of blade, blade thickness, length of blades, shaft diameter, etc. The clearance between the blades and concave sieve (concave clearance) in the husking chamber influences the husking efficiency and seed damage. It was observed that increase in the clearance would result in low husking efficiency; whereas, reduced clearance would cause seed damage. Therefore, various concave clearances were tried to determine the optimum clearance; while, the sieve sizes were based on axial dimensions of the fruits and seeds. The machine was powered with 0.5 hp AC motor and had overall dimensions of 1250 mm length, 1100 mm height and a width of 500 mm.

Determination of energy required to husk Jatropha fruit: Based on Kick's Law, the energy required to reduce a material in size was directly proportional to the size reduction, Equations (4) and (5).

$$E = K_k . f_c \log_e \left(\frac{L_1}{L_2}\right) \qquad (4)$$

$$P = m . K_k . f_c . \log_e \left(\frac{L_1}{L_2}\right) \qquad (5)$$

Where

E = energy required to husk fruit,
P = power required to husk the fruit,
K_K = kick's constant = 1.2,
m = husking capacity = 80 kg h^{-},
f_c = crushing strength of Jatropha fruit (N) = 79 N = 4390 kg m^{-},

VOL. 11, NO. 3, MARCH 2016 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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L_1 = average thickness length of Jatropha fruit before husking,
L_2 = average thickness length of Jatropha after husking.

The value of the power obtained using Equation (5) is H = 0.0128 kW.

Considering the transmission efficiency, the required motor power (H_m) is given as by Equation (6):

$$H_m = \frac{H}{Efficiency} \quad (6)$$

Where
H_m = motor power. Assuming the power transmission efficiency is 80%. The value obtained by calculations using Equation (6) was 0.0161 kW = 0.0216 hp.

Determination of the power required for the shaker

Shaker speed: Forcing the fruits to move in the shaker plate required an acceleration force of greater value than the friction force between plate and fruits (i.e. $F_a > F_f$) as indicated by Equation (7).

$$W \geq \sqrt{\frac{g\mu}{r\cos\theta}} \quad (7)$$

Where:
F_a = acceleration force acting on fruit,
F_f = friction force between plate and fruits,
μ = friction coefficient between fruit and plate = 0.14,
g = gravity (9.81),
r = shaker crank radius = 0.4,
θ = the angle crank in which fruit release, θ = 40 °,
W = shaker shaft speed.

Shaker power: The power required to move the shaker must be greater than the power needed to break the Jatropha fruit, Equation (8).

$$P = F \times V \quad (8)$$

Where:

P = power required for the shaker,
F = force required to move the shaker,
V = speed of the shaker = 1.25 m s^{-1},

The value is obtained using Equation (8) was found to be P = 0.1837 kW = 0.249 hp

Selection of the motor power required for the Husking Machine: Total power needed for husking Jatropha fruit, from Equations (6) and (8) = 0.2714 hp. Therefore, based on the value of the total power needed to rotate the drum and the fan (0.2714 hp); and for safety, a motor of 0.5 hp at 1500 rpm must be used.

Determination of diameter and drum speed for the Husking Machine: The velocity ratio related to the diameter ratio and speed ratio is given by Equation (9).

$$V.R = \frac{D_d}{D_m} = \frac{N_m}{N_d} \quad (9)$$

Where
D_d = effective diameter of driven pulley, m,
D_m = effective diameter of drive pulley, m,
N_d = drum speed, rpm,
N_m = motor speed, rpm =1500 rpm,
V.R. = velocity ratio.

Assuming a speed ratio of 5 and an effective diameter of the driven pulley of 60 mm, the speed and the diameter of the drum were obtained using Equation (9) as 300 rpm and 300 mm, respectively.

Determination of the torque developed by the Husker: The torque developed by the Husker shaft was obtained from the relation given in Equation (10).

$$M_t = \frac{9550\ kW}{N_m\ rpm} \quad (10)$$

Where
M_t = tensional moment,

For the husking machine N_m =1500; hence, the torque was obtained using Equation (10) and found to be M_t = 6.3 N.m,

The driven pulley load is given by Equation (11).

$$T = \frac{M_t}{D_p} \quad (11)$$

Where
T = driven pulley load, N,
D_p = diameter driven pulley, mm.

For the husking drum, D_p = 300 mm, the driven pulley load was obtained using Equation (11) as T = 21.2 N. Hence, the vertical and horizontal components of belt tension are given by Equations (12) and (13).

$$T_V = T \sin 40 \quad (12)$$

$$T_H = T \cos 40 \quad (13)$$

Where
T_V = the vertical belt tension, N,
T_H = the horizontal belt tension, N.

The values of the husking loads were obtained using Equations (12) and (13) as T_V = 13.6 N and T_H = 16.2 N.

The motor pulley circumferential speed is given as by Equation (14).

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$$V = \frac{\pi d n}{60} \quad (14)$$

The motor's pulley circumferential speed was obtained using Equation (14) as V = 4.7 m s^{-1}.

Belt selection for the motor of the Husking Machine: The required belt length is obtained from relation given by Equation (15).

$$L = 2C + 1.57(D - d)\frac{(D - d)^2}{4C} \quad (15)$$

Where

C = the distance between driving and driven pulleys,
D and d = the diameter of driver and motor pulleys, respectively.

The value of the belt length obtained using Equation (15) was L = 1.69 m.

Determination of number of belts: The required number of belts to transmit the developed power (n) was determined using Equation (16).

$$n = \frac{H}{H_t} \quad (16)$$

Where

H = power required for husking Jatropha fruit,
H_t = power transmitted by a section of belt.

The number of belts was obtained using Equation (16) and found to be n = 1.

Determination of Husker shaft loads and reactions: Reactions, loading and bending moment were calculated by horizontal and vertical diagram (Figures 2, 3, 4 and 5) with strong outcome calculated in the vertical direction of the Husker as follows:

With reference to Figure-3, the summation of forces in the vertical direction is given by Equation (17).

$$\sum Fr = R_{AV} + R_{BV} - F_{1V} - F_{2V} - F_{3V} - F_{4V} = 0 \quad (17)$$

With reference to Figure 5, the summation of forces in the horizontal direction is given by Equation (18).

$$\sum Fr = R_{AH} + R_{BH} - F_{1H} - F_{2H} = 0 \quad (18)$$

The reaction values were obtained using Equations (4) and (6) and they were found to be R_{AV} = 118.24 N, R_{BV} = -5.53 N, R_{AH} = 113.12 N, and R_{BH} = -18.31 N.

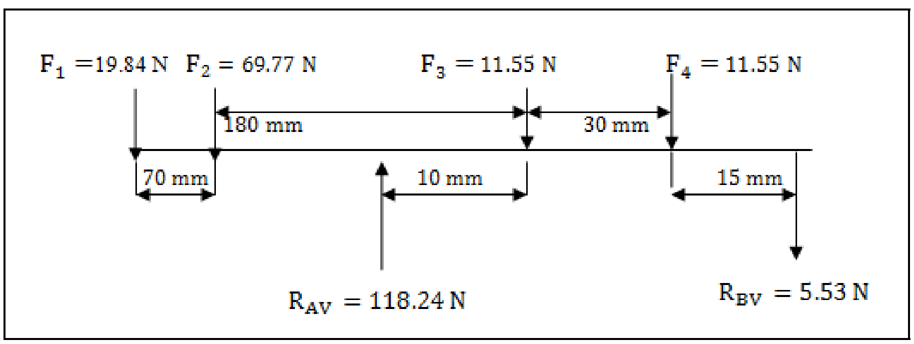

Figure-2. Husker shaft loading in the vertical plane.

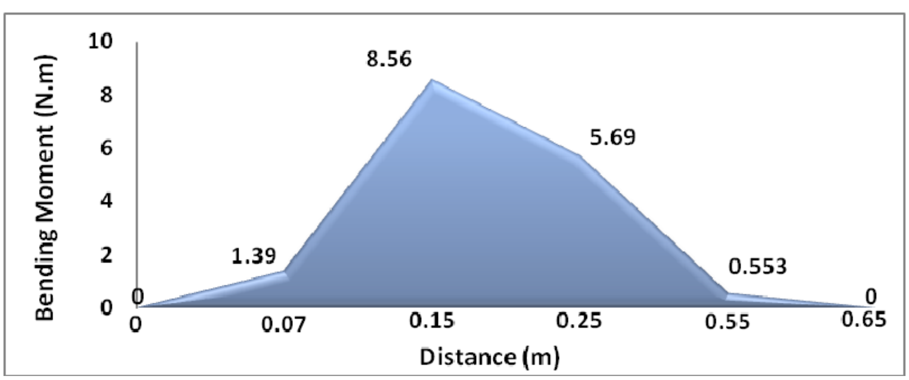

Figure-3. Husker shaft bending moment diagram in the vertical plane.

VOL. 11, NO. 3, MARCH 2016 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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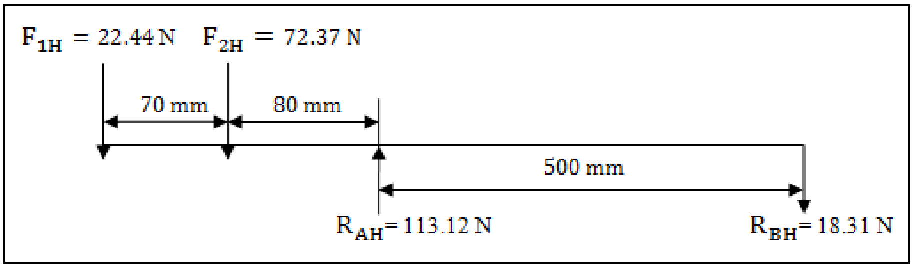

Figure-4. Husker shaft loading in the horizontal plane.

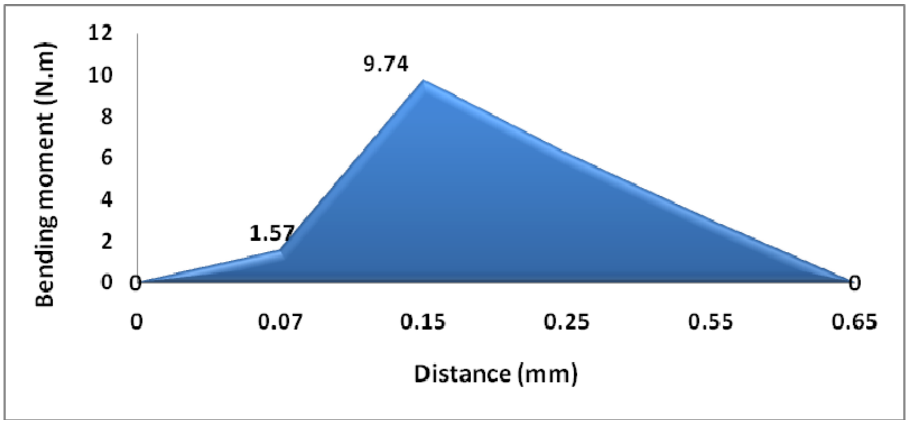

Figure-5. Husker shaft bending moment diagram in the horizontal plane.

Determination of the drum shaft diameter: The diameter of the drum shaft was calculated using Equation (19).

$$D_S = \sqrt[3]{\left[\left(\frac{N}{\pi\tau_s}\right)(M_b K_b)^2 + (M_t K_t)^2\right]^{1/2}} \quad (19)$$

Where

D_S = Diameter of the drum shaft, m,
M_b = Resultant bending moment, N.m,
M_t = Tensional moment, N.m,
K_b = Dimensionless, combined and fatigue factor applied to bending moment,
K_t = Dimensionless, combined and fatigue factor applied to tensional moment,
τ_s = Allowable shear stress of the shaft, MN m^{-2}.

The resultant bending moment (M_b) was calculated as 13 N.m by analyzing the moments exerted by both horizontal and vertical loads in the bending moment diagrams of the shaft shown in Figures 3 and 5. Using drums weight (steel) of 7.5 kg, Pulleys weight (aluminum) of 5.7 and 0.64 kg, Steel density of 8750 kg m^{-3} and aluminum density of 2700 kg m^{-3}, P = 746 W and N = 1500 rpm. The tensional moment (M_t) was calculated as 6.3 N.m. The values of K_b and K_t were taken as 1.5 and 1.0, respectively, for the gradually applied load on the rotating shaft. The allowable shear stress of the shaft (S_s) was estimated at 35 MN m^{-2} based on the ASME code. The values of the diameter were determined using Equation (19) and found to be D_s = 14.3 mm. Using a factor of safety of 0.5, the selected value of the shaft diameter (D_S) of 25 mm was used.

Assessment of the performance of the developed Jatropha husking machine

Performance assessment of the developed machines was carried at the Lab facility of the Agricultural Engineering Department, Faculty of Engineering, University of Khartoum. Random samples (3 kg each) of Jatropha fruits were used for the assessment process. The samples were hand fed into the husking machine through the hopper. The time taken to husk the sample, the seeds weight, the husks weight, and the weight of the husks mixed with the seeds, were recorded. This procedure was repeated six times and the values of the above mentioned parameters were recorded each time. The collected observations were used to calculate various performance indicators, such as: (i) cleaning efficiency, (ii) husking efficiency, (iii) husking capacity, (iv) husking percentage, and (v) whole seeds percentage.

Cleaning efficiency: Cleanliness is the ability of the blower to effectively separate the husks from the seeds without leaving any husk in the seeds. Cleaning efficiency (%) was determined by Equation (20).

$$\text{Cleaning efficiency} = \left(1 - \frac{W_{sk}}{W_t}\right) \times 100 \quad (20)$$

Where
W_{sk} = weight of husk in output seeds, kg,
W_t = Total weight of the sample, kg,

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Husking efficiency: The husking efficiency (%) was determined by Equation (21).

$$\text{Husking efficiency} = \frac{W_t - W_l}{W_t} \times 100 \quad (21)$$

Where
W_1 = weight of the un-husked fruits in sample, kg.

Husking capacity: The husking capacity (kg h^{-1}) was calculated using Equation (22).

$$\text{Husking capacity} = \frac{W_t}{T} \quad (22)$$

Where
T = time required to husk the sample, h.

Husks percentage: The husking percentage was calculated using Equation (23).

$$\text{Husks percentage} = \frac{W_{ws}}{W_t} \times 100 \quad (23)$$

Where
W_{ws} = weight of husks in the sample, kg.

Whole seeds percentage: The Whole seeds percentage was calculated using Equation (24).

$$\text{Whole seeds percentage} = \frac{W_{wk}}{W_t} \times 100 \quad (24)$$

Where
W_{wk} = the weight of cleaning seeds in sample, kg.

RESULTS AND DISCUSSIONS

Engineering properties of Jatropha fruits

Summary of the descriptive statistic results of engineering properties of Jatropha fruits and seeds are presented in Table-1. The observations included length, width and thickness for both fruits and seeds. From Table-1, it was found that the mean values of the length, width and thickens of Jatropha fruit before husking were 26.49 ± 8.07 mm, 21.088 4.92 mm, and 19.280 ± 4.68 mm, respectively. While Jatropha fruit after husking (seeds) showed an average length, width, and thickness of 24.49 ± 8.07 mm, 19.088 ± 4.92 mm, and 17.28 ± 4.68 mm, respectively.

Table-1. Descriptive statistics for Jatropha fruit before and after husking.

Parameter	Fruit before Husking			Fruit after Husking (Clean seeds)		
	Length mm	Width mm	Thickness mm	Length mm	Width mm	Thickness mm
Minimum	20.90	17.25	24.49	18.90	15.25	12.96
Maximum	32.08	24.49	22.81	30.08	19.08	17.28
Mean	26.49	21.08	19.28	24.49	19.0889	17.28
Std. Error	0.2693	0.1642	0.1598	0.2693	0.1642	0.1598
Std. Deviation	2.693	1.641	1.598	2.693	1.641	1.593
Variance	7.254	2.695	2.555	7.254	2.965	2.555
Skewness	-0.054	0.002	0.161	-0.54	0.002	0.161
Std. Error	0.241	0.241	0.241	0.241	0.241	0.241
Kurtosis	-0.885	-1.025	-0.281	-0.885	-1.025	-0.281
Std. Error	0.478	0.478	0.478	0.478	0.478	0.478

The other physical properties of Jatropha fruits seeds and kernels were also investigated and the summarized results are presented in Table-2. The results for sphericity indicated that the seeds were 7% more spherical than the kernels. The sphericity values for both Jatropha seeds and kernels were observed to be 66% and 59%, respectively. Hence, these results are in agreement with previous studies that both the Jatropha seeds and kernels must not be characterized to have spherical geometry, since their sphericity values were below 0.7 (Pradhan *et al*., 2009b; Davies, 2010).

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Table-2. Physical and mechanical properties of Jatropha fruit, seed and kernel.

Property	N	Fruit	Seed	Kernel
Oil content, %	5	20.12 ± 2.11	38.32 ± 4.61	45.03 ± 7.86
Moisture content, %	5	7.79 ± 0.56	5.85	6.35 ± 0.04
Length, mm	100	26.49 ± 2.69	18.56 ± 0.83	15.23 ± 0.78
Width, mm	100	21.08 ± 1.64	11.37 ± 0.40	8.85 ± 1.25
Thickens, mm	100	19.28 ± 1.60	8.68 ±0 .46	7.11 ± 0.60
Geometric mean diameter, mm	100	21.801	12.23	8.41 ± 1.25
Sphericity, %	100	84.29%	65.79%	59% ± 6
1000 unit mass, g	20	2,280.35 ± 13.26	761.50 ± 3.25	476.17±. 254
Seed friction, % [(a)]	20	71.68 ± 7.35	100	NA
Kernel friction, % [(a)]	20	44.73 ± 5.36	63.02 ± 5.78	100
Husk/Shell friction, % [(a)]	20	28.32 ± 7.35	37.13 ± 4.11	0
Surface area, mm^2 [(a)]	100	1834.40 ± 77.73	486.94 ± 15.67	221.91 ±12.63
Bulk density, kg m^{-3} [(a)]	20	278 ± 1.01	476 ±1.97	588.29 ± 3.84
True density, kg m^{-3} [(a)]	20	546 ± 5.47	711 ± 7.97	865.87 ± 9.23
Porosity, % [(a)]	20	49.80 ± 0.8	33.05 ± 0.11	32.06 ± 2.67
Loading position [(b)]		Horizontal	Horizontal	
Rupture force, N [(b)]		79.0 (25.08)	113.99 (19.24)	
Deformation Rupture point, mm [(b)]		----	2.05 (1.10)	
Hardness, N mm^{-1} [(b)]		-----	67.75 (7.02)	

Sources: *[(a)] Pradhan et al. 2009b, [(b)] Bamgboye and Adebayo (2012).*

Development of Jatropha fruits husking machine

Jatropha fruits husking machine for bio-fuel production in rural areas have been successfully designed, developed and evaluated, Figure-6. The developed machine main components included: (i) the feed trough through which the Jatropha fruits are fed into the husking machine, (ii) husking unit which consists of a drum and (iii) a cleaning unit consists of a sieve, a belt, pulleys and transmission motor power. The husking machine main frame, on which other parts of the husker were fixed, was made from skewer mild steel; while the housing of the husking machine was made from steel and the hopper was constructed from sheet metals. An AC motor of 0.5 hp was used as the prime mover that supplied power to the husker through a belt drive mechanism. The husking process is achieved by means of husking bars on the drum by both rubbing and beating actions against a stationary plate (a concave). Clean seeds are obtained by the sieving unit in the developed machine. The developed machine had overall dimensions of 1250 mm in length, 1100 mm in height and a width of 500 mm. The fabricated machine (Figure-6) was conceived as low-cost, easy to adjust, easy to dismantle and easy to fabricate. The hopper, of conical shape, is mounted on the frame and held in place by a hopper support frame. The husking chamber consists of rotating blades mounted on shaft. Husking Jatropha fruits can be accomplished different methods such as impact, rubbing, squeezing or a combination of the three. Between the three methods, the rubbing action would produce seeds with minimal damage, it is essential to apply least impact with rubbing action. The husking chamber was designed in such a way that it creates more rubbing action. The seeds and husks from the husking chamber will be collected in the discharge outlet and transferred to the vibrating separator. The separator consisted of two layers of sieves with ob-long openings (12 × 19 and 6 × 9 mm) for the separation of seeds and husks.

Components of the developed husking machine

(a) The frame: It supports the entire machine and was made by joining 550 mm x 550 mm x 500 mm x 500 mm iron into the final shape by welding. It carries the prime mover, the husking unit, and the cleaning unit.

(b) The hopper: This structure is the unit through which Jatropha fruits to be husked is fed and channeled into the husking chamber. It was made of 500 mm x 470 mm metal sheet which tippers towards the husking mechanism for easy flow of the materials by gravity.

(c) The husking unit: Consists of a circular-shaped drum made of steel skewer and clasped, and a concave also made of the skewer; is used for separating the outer layer of the fruit by bombardment with the drum.

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(d) Cleaning unit: The cleaning unit is used to separate the seeds from the husk by means of vibration process, so inseparable seeds will be transferred to the bowl through the slots.

Figure-6. The developed Jatropha husking machine.

Technical specifications of the developed Husking machine

The technical specifications of the developed husking machine are shown in Table-3.

Table-3. Technical specifications of the developed Jatropha husking machine.

Item	Specifications
Machine overall dimensions	1250 x 500 x 1100 mm
Diameter of larger pulley	300 mm
Diameter of small pulley	60 mm
Motor speed / power	1500 rpm / 0.5 hp
Husking speed	300 rpm
Motor pulley circumferential speed	4.7 m s^{-1}
Number of belts	1
Drum shaft diameter	25 mm
Shaker cam shaft diameter	200 mm
Shaker speed	60 rpm

Assessment of the performance of the developed husking machine

The developed Jatropha fruits husking machine has been tested and evaluated and led to successful results with high efficiency. Figure-7 shows the fruits before husking, the clean seeds after husking operation and the outlet husks. The results of the husking machine were presented in Table-4, including the cleaning efficiency, the husking efficiency, husking capacity, husks recovery and whole seeds recovery. Descriptive statistics analyses results of the developed husking machine is shown on Table-5. The mean values of the cleaning efficiency, husking capacity, husks percentage and whole seeds percentage were 91.78 ± 1.97%, 44.058 ± 2.79 kg h^{-1}, 34.24 ± 0.942% and 61.99 ± 3.52%, respectively; while the husking efficiency was 100%.

Table-4. Performance results of the developed Jatropha husking machine.

Performance parameter	Test number						Average
	1	2	3	4	5	6	
Cleaning efficiency %	92.67	91.33	92.33	91	91.33	92	91.78 ± 0.657
Husking efficiency %	100	100	100	100	100	100	100
Husking capacity, kg h^{-1}	45.86	43.2	44.08	43.9	43.72	43.59	44.058 ± 0.932
Husks percentage, %	34.5	34.67	33.83	34	34.16	34.33	34.24 ± 0.314
Whole seeds percentage, %	59.66	62.66	62.66	62	62.33	62.66	61.99 ± 1.174
Trash percentage, %	5.83	2.17	3.51	4	3.5	3.01	3.670 ± 1.226
Loss in weight Percentage, %	0.01	0.05	0	0	0.01	0	0.0117 ± .019

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Table-5. Descriptive statistics for the husking process output.

Parameter	Cleaning efficiency, %	Husking efficiency, %	Husking capacity, kg h^{-1}	Husks, %	Whole seeds, %	Trash, %	Weight Loss, %
Range	1.67	0.00	2.66	0.84	3.00	3.66	0.05
Minimum	91.00	100.00	43.20	33.83	59.66	2.17	0.00
Maximum	92.67	100.00	45.86	34.67	62.66	5.83	0.05
Mean	91.78	100.00	44.058	34.248	61.995	3.670	0.0117
Std. Error	0.268	00.00	0.380	0.128	0.479	0.501	0.008
Std. Deviation	0.657	00.00	0.932	.31378	1.174	1.226	0.0194
Variance	0.431	00.00	0.868	0.098	1.378	1.503	0.000
Skewness	0.261	.	1.880	0.022	-2.190	1.049	2.116
Std. Error	0.845	.	0.845	0.845	0.845	0.845	0.845
Kurtosis	-1.822	.	4.091	-1.184	4.926	2.128	4.678
Std. Error	1.74	.	1.741	1.741	1.741	1.741	1.741

Figure-7. (A) Jatropha fruits before husking; (B) Clean seeds after husking; and (C) Output husks after husking.

CONCLUSIONS

The following conclusions could be drawn from the results of this study:

- Engineering properties for Jatropha fruits and seeds have been successfully studied.
- Jatropha husking machine for bio-fuel production in rural areas have been successfully designed, developed and evaluated.
- The obtained results from husking machine showed that the mean values of the cleaning efficiency, husking capacity, husks percentage and whole seeds percentage were 91.78 ± 1.97%, 44.058 ± 2.79 kg h^{-1}, 34.24 ± 0.942% and 61.99 ± 3.52%, respectively; while the husking efficiency was 100%.

ACKNOWLEDGEMENTS

This study was financially supported by King Saud University, through the Vice Deanship of Research Chairs. The authors are very grateful to the Faculty of Engineering, University of Blue Nile and the Department of Agricultural Engineering, Faculty of Engineering, University of Khartoum, for using their workshops and Lab facilities.

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