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Development and Performance of a Jatropha Seed Shelling Machine Based on Seed Moisture Content

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Abstract

Purpose: The high energy requirement of extraction of oil from jatropha seed and reduction of loss in oil content between whole seed and kernel of jatropha necessitate seed shelling. The purpose of this study is to develop and evaluate the performance of a jatropha seed shelling machine based on seed moisture content. **Methods:** A shelling machine was designed and constructed for jatropha seed. The components are frame, hopper, shelling chamber, concave, and blower with discharge units. The performance evaluation of the machine was carried out by determining parameters such as percentage of whole kernel recovered, percentage of broken kernel recovered, percentage of partially shelled seed, percentage of unshelled seed, machine capacity, machine efficiency, and shelling efficiency. All of the parameters were evaluated at five different moisture levels: 8.00%, 9.37%, 10.77%, 12.21%, and 13.68% w.b.). **Results:** The shelling efficiency of the machine increased with increase in seed moisture content; the percentage of whole kernel recovered and percentage of partially shelled seed decreased with increase in moisture content; and percentage of broken kernel, machine efficiency, and percentage of unshelled seed followed a sinusoidal trend with moisture content variation. **Conclusion:** The best operating condition for the shelling machine was at a moisture content of 8.00% w.b., at which the maximum percentage of whole kernel recovered was 23.23% at a shelling efficiency of 73.95%.

Keywords: Efficiency, Jatropha seed, Kernel, Moisture content, Shelling

Introduction

Jatropha curcas is a drought-resistant perennial crop that grows well in marginal land. Jatropha, known as the "wonder plant," produces seeds with an oil content of 37%. The oil can be combusted as fuel without being refined; it burns with a clear, smoke-free flame; and it has been tested successfully as fuel for simple diesel engines. Jatropha cake kernel is used as fertilizer (CJP, 2009). Jatropha has potential for controlling soil erosion. It does not require any particular soil type for growth and can flourish in almost any soil composition.

Dry *Jatropha curcas* fruit contains about 37.5% pod and 62.5% seed, and the seed contains about 42% shell and 58% kernel. The seed kernel contains about 40–60% (w/w) of oil. Extraction of oil from jatropha seeds can be done by mechanical means, such as with a screw press (Amoah, 2012). To obtain kernels of seeds for oil extraction, the fruits are dried and decorticated to obtain the seeds, after which the seed undergoes a shelling process in order to obtain the kernel that contains the oil. Pradhan et al. (2010) developed a hand-operated jatropha fruit decorticator with a machine efficiency of 90.96%; the maximum percentage of whole seed recovered was 67.94%, which is quite acceptable. However, the seed shell is removed manually by using simple tools like pliers, stones, and sticks (Amoah, 2012). When shelling is done manually, it is labor-intensive and involves a lot of drudgery. Further, when the seed shell is not removed, it implies a loss of

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energy in the form of retained oil in the seed cake and the loss of seed shell, which is a source of fuel (Amoah, 2012). In addition, a greater amount of energy is required to extract oil from jatropha seed; Karaj and Muller (2011) reported that 1 kWh of energy is required in extracting 1.4 kg of jatropha seed oil from seeds, with a capacity of 2.76 kg/h, indicating a machine operation energy requirement of 1.97 kWh, whereas Ting et al. (2012) showed a machine operation energy requirement of 0.460 kWh for extraction of oil from jatropha kernel. The jatropha plant as a viable source of biofuel has attracted research interest, and it has been discovered that all products from the jatropha plant are useful. Many researchers have reported that the shell of the jatropha seed serves as a source biomass for several purposes (Openshaw, 2000; Wever et al., 2012; Kratzeisen and Müller, 2009). Wever et al. (2012) also showed that the shell of the jatropha seed could be used in the production of particleboard. Openshaw (2000) reported that after jatropha plant has reached full capacity in six years, a hectare of jatropha plant will give a yield of 1.8 tonnes of jatropha seed shell and 3.45 tonnes of seed per annum. Optimum use of the jatropha plant would promote interest in this crop. Such optimum use could be realized by the availability of processing machines that make jatropha kernel and the by-product of jatropha seed usable for other purposes, such as particleboard and biodiesel production and biomass. That interest brought about the development of a machine that could shell jatropha seed. The main objectives of this work were to design and fabricate a jatropha-seed-shelling machine by using a cylindrical shelling mechanism and to evaluate the machine's performance.

Materials and Methods

Designs of machine parts

The various components of the jatropha-seed-shelling machine were designed following required standards as described next.

The hopper

The hopper is the machine component through which the seeds are introduced into the machine. A pyramid-shaped hopper was designed using necessary parameters such as static coefficient of friction and angle of repose in the jatropha seed.

Shaft design

The shaft is a mechanical-device component that transmits rotational motion and power. The power is transmitted by tangential force and the resulting torque setup within the shaft, which permits the power to be transferred to various elements linked to the shaft. The various members such as pulley, bearing, and drum are mounted on it. The members along with the force exerted upon them cause the shaft to bend. Therefore, it is necessary to design the shaft of the machine so as to obtain a shaft diameter that can withstand failure in any case. The following assumptions were made:

1. The shaft is made of mild steel.
2. The load on the drum is uniformly distributed on the shaft, and the material is homogenous.
3. The shaft experiences both torsion and bending as well as allowable stresses in the material that do not exceed 40 MN/m^2 (ASME code).

The diameter of the shaft under load, torsion, and bending moment simultaneously was found by using the following expression in equation 1 (ASME).

$$D^3 = \frac{16}{\pi s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{1}$$

where D = the diameter of the shaft
S = the allowable stress = 40 MN/m
M_b = the bending moment of the shaft = 6.192 Nm
K_b = the combined shock and fatigue factor applied to bending moment
K_t = the combined shock and fatigue factor applied to moment of torsion
M_t = the moment of torsion of the shaft calculated

For load applied gradually on rotating shaft, K_b = 1.5 and K_t = 1.0 (Shittu and Ndrika, 2012; Aaron, 1975). The right diameter for the shaft was evaluated to be 17.3 mm. Therefore, that is the minimum diameter that can carry the applied load while not exceeding the allowable stress.

Belt design

In the belt design, an A-type V-belt was used in the transmission of power and torque from the prime mover. Two belts were connected to the prime mover to drive the shafts with the shelling drum as well as the fan. According to Aaron (1975), the relationship between the speed and pulley diameters can be shown as in equation 2.

$$N_1 D_1 = N_2 D_2 \tag{2}$$

The speed at the shelling unit was evaluated, and the rated speed of engine N_2 was found to be 1440 rpm. The belt length for an open drive was determined according to the relationship given by Srivastava et al. (2006) as expressed in equation 3.

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{2C} \tag{3}$$

where N_1 = speed of driven pulley, rpm
N_2 = speed of driving pulley, rpm
D_1 = sheave diameter of driving pulley, mm
D_2 = sheave diameter of driven pulley, mm
L = belt length, mm
C = distance between the centers of driving and driven pulleys, mm

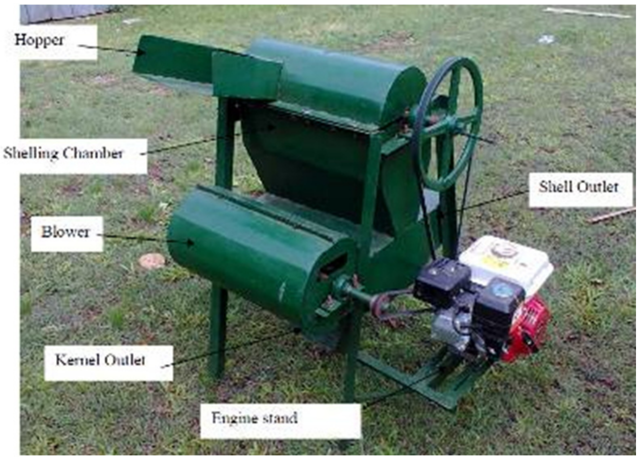

Figure 1. Jatropha-seed-shelling machine.

Description of machine parts

The various components of the jatropha-seed-shelling machine are described next. Figures 1 and 2 show pictorial, side, and front views of the machine.

The support frame

The main frame was constructed with angle iron. Angle irons were welded together to form the framework. The welding results in very rigid joints—which is in line with the modern trend toward rigid frames—and the strength and rigidity for the overall machine parts as shown in Figure 1.

The shelling chamber

The shelling chamber consists of the shaft with the shelling drum as well as the screen. The shelling drum was constructed from a mild steel plate that was rolled and made into a cylinder. The shaft was made to pass through the rolled cylindrical sheet and welded in place with two circular discs. The screen was made from a mild steel rod having a diameter of 8 mm. The unit is shown in Figure 1.

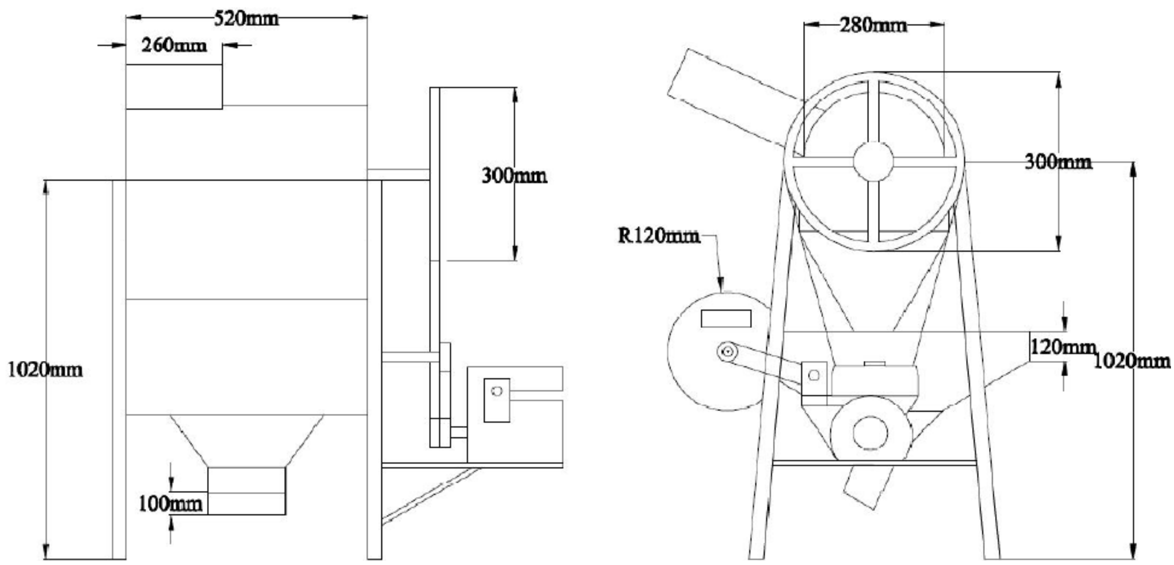

Figure 2. Front and side views of the jatropha seed shelling machine.

The blower

The blower produces air that separates the seed shell from a kernel-shell mixture after shelling has taken place. This unit of the machine blows away the jatropha seed shell through the shell outlet while allowing the jatropha kernel to fall through without any interference. The speed of the blower was regulated by applying the aerodynamic properties of both jatropha kernel and shells in such a way that the kernel would not be blown away as the shell is being blown off.

The engine and the pulley system

An engine was used to power the machine. A pulley system was used to transmit power the through belts to the blower at a high speed and to the drum at reduced speed and increased torque. The reduced speed at the shelling drum was aimed at shelling the seeds with minimum breakage.

The discharge unit

There are two outlets in the machine: the shell delivery outlet and the kernel delivery outlet. The two discharge units were designed in such a way that shell coming out from the machine is properly discharged without getting mixed with the kernel.

Performance evaluation

The jatropha seed shelling machine was subjected to certain tests to determine its performance. The machine was evaluated based on the following procedures.

Sample preparation

In the testing of the jatropha-seed-shelling machine, the seeds were conditioned to five moisture levels as had been done by other researchers (Shittu and Ndrika, 2012; Pradhan et al., 2010). The first moisture level is the natural moisture content of the seeds; other moisture levels were conditioned by adding water. Samples were moistened with a calculated quantity of water (5 g, 10 g, 15 g, and 20 g) and conditioned to raise their moisture content to the four desired levels. The seeds were thereafter stored in cellophane for three hours for uniform distribution moisture within the seed shell structure. The moisture content values and the range selected were based on what is obtainable in the literature as well as on the nature of the seed during shelling. Moreover, the values selected followed the conventional trend for moisture content selection. In most cases, the seed brittleness tends to increase as moisture content decreases, thereby leading to kernel breakage, whereas with an increase in seed moisture content, the seed becomes more ductile, thereby contributing to low levels of kernel breakage during shelling. The experiment was carried out by measuring 400g sample of *Jatropha curcas* seeds that had been conditioned to the desired moisture level according to the expression in equation 4. The machine test was replicated three times for each moisture level, as carried out by Pradhan et al. (2010).

$$b = \frac{100Q + Aa}{A - Q} \tag{4}$$

where b = the desired moisture content
Q = the quantity of water added to the jatropha seed
A = the mass of jatropha seed
a = the actual moisture content of the seed

Determination of percentage of whole kernel recovered

The percentage of whole kernel recovered was found as the mass of the whole kernels recovered from the kernel shell mixture after shelling. It is the proportion of the mass of whole kernels to the actual mass of kernel present in the seed introduced into the machine. It was computed using the expression in equation 5 (Pradhan et al., 2010).

$$Percentage\ of\ whole\ kernel\ recovered = \frac{Mass\ of\ the\ whole\ kernel}{Total\ mass\ of\ kernel\ in\ the\ sample} \times 100 \tag{5}$$

Determination of percentage of broken kernel recovered

The percentage of broken kernels recovered was also found. This is the proportion of broken kernel to the actual mass of kernel present in the seed introduced into the machine. It was computed using the expression in equation 6 (Oluwole et al., 2007).

$$Percentage\ of\ broken\ kernel\ recovered = \frac{Mass\ of\ the\ broken\ kernel}{Total\ mass\ of\ kernel\ in\ the\ sample} \times 100 \tag{6}$$

Determination of percentage of unshelled seed recovered

This is the ratio of the mass of the unshelled seed to that of the seeds introduced into the machine. It was computed using the expression in equation 7 (Atiku et al., 2004).

$$Percentage\ of\ unshelled\ seed = \frac{Mass\ of\ the\ unshelled\ seed}{Total\ mass\ of\ the\ seed\ sample} \times 100 \quad (7)$$

Determination of percentage of partially shelled seed recovered

This is the ratio of the mass of the seed that is not completely shelled to the mass of seeds introduced into the machine. It was computed using equation 8.

$$Percentage\ of\ partially\ shelled\ seed = \frac{Mass\ of\ seed\ not\ completely\ shelled}{Total\ mass\ of\ the\ sample} \times 100 \quad (8)$$

Determination of shelling efficiency

Shelling efficiency is the ability of the shelling mechanism to effectively shell *Jatropha curcas* seeds. It was evaluated using equation 9, as had been done by Pradhan et al. (2010).

$$Shelling\ efficiency = \left[1 - \frac{M_U + M_P}{M_O}\right] \times 100 \quad (9)$$

where M_U = the mass of unshelled seed recovered after shelling
M_P = the mass of seed partially shelled recovered after shelling
M_O = the total mass of the sample introduced into the machine

Determination of machine efficiency

Overall machine efficiency was also found. This was evaluated using the expression in equation 10.

$$Machine\ efficiency = \left[1 - \frac{M_U + M_P}{M_O}\right] \times \left[\frac{M_W}{M_W + M_B}\right] \times 100 \quad (10)$$

where M_W = the mass of whole kernel
M_B = the mass of broken kernel

Machine capacity

This is the ratio of the sum of whole kernel and broken kernel recovered to the time taken for the shelling operation. The capacity of the machine was computed using the relationship in equation 11.

$$Machine\ capacity = \frac{Total\ mass\ of\ the\ kernel\ recovered}{Shelling\ time} \quad (11)$$

Results and Discussion

Performance of the jatropha-seed-shelling machine

Table 1 shows the results of the performance test of the shelling machine at different moisture contents. The performance parameters such as percentages of whole kernel, broken kernel, partially shelled seed, and unshelled seed vary with change in moisture content as shown in Figures 3 – 6.

The maximum value for the percentage of whole kernel recovered was found to be 23.23% at a moisture content of 8.00% (w.b.), and a minimum value of 17.23% at moisture content of 12.21% (w.b.). Those values compare favorably with values obtained for jatropha seed shelling using a roller mechanism (Ting et al., 2012), who obtained a maximum value of 31.50% for percentage of whole kernel recovered using a roller shelling mechanism. The

Table 1. Performance of jatropha seed shelling machine

Moisture content (% w.b.)	Whole kernel percentage (%)	Broken kernel percentage (%)	Unshelled seed recovered (%)	Partially seed shelled (%)
8.00	23.23	31.17	15.29	10.76
9.37	19.99	29.92	14.44	10.72
10.77	19.91	31.93	12.34	7.93
12.21	17.23	33.65	12.77	8.78
13.68	18.74	30.30	13.64	6.63

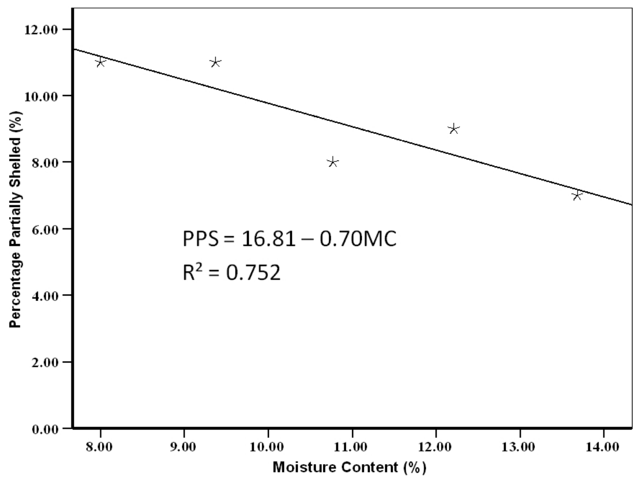

Figure 3. Effects of moisture content variation on percentage partially shelled.

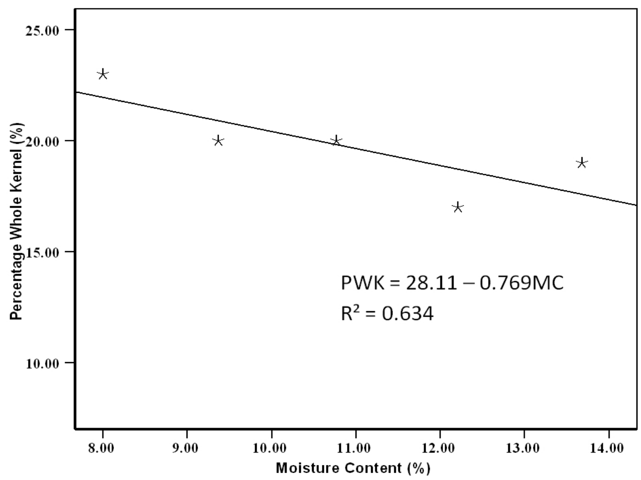

Figure 4. Effects of moisture content on percentage whole kernel.

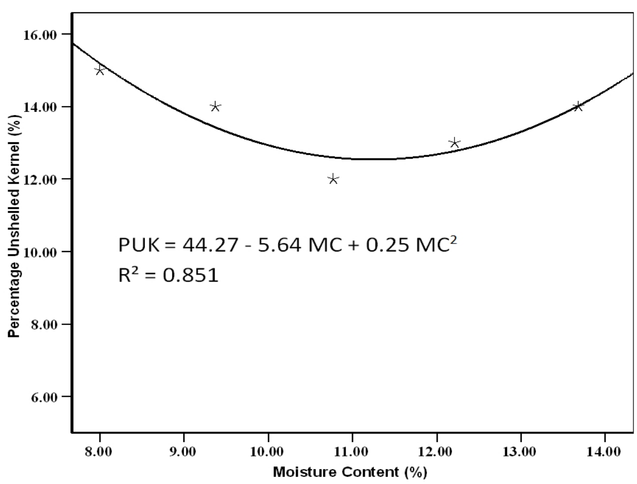

Figure 5. Effects of moisture content on percentage unshelled kernel.

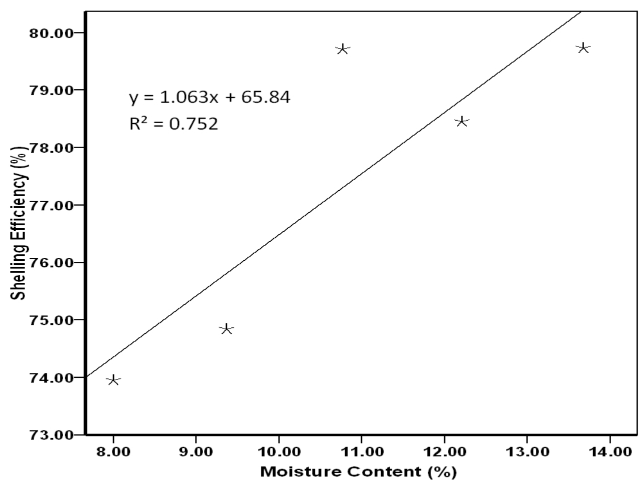

Figure 6. Effects of moisture content variation on shelling efficiency.

values obtained using a rasp-bar-cylinder shelling mechanism are caused by the fact that at high moisture content, the kernel becomes more brittle and soft and thus susceptible to mechanical damage—similar to assertions by Pradhan et al. (2010). Moreover, the percentage of whole kernel tends to decrease with an increase in moisture content, as shown in Figure 2. The percentage of broken kernel has a minimum value of 29.92% at a moisture content of 9.37% (w.b.) and maximum value of 33.65% at a moisture content of 12.21% (w.b.), because at low moisture content, the kernel tends to maintain its size; but when its moisture content increases, it swells up and thus assumes the quasi-size of the seed, which leads to breakage of the kernel. The rasp-bar cylinder shelling mechanism is preferable to the roller mechanism because of the occurrence of kernels' being crushed with their shell in the roller shelling mechanism, which makes it difficult for the shell to be separated from the kernel after shelling.

The percentage of partially shelled seed also has a minimum value of 6.63% at a moisture content of 13.68%. (w.b.) and a maximum value of 10.76% at moisture content of 8.00% (w.b.). Similarly, the percentage of unshelled seed has a minimum value of 12.34% at a moisture content of 10.77% (w.b.), and a maximum value of 15.29% at a moisture content of 8.00% (w.b.). Table 1 shows values obtained for the performance indicators. It can be seen that the percentages of whole kernel and broken kernel decrease linearly from 23.23% to 18.74% with the increase in moisture content from 8.00% to 13.68% (w.b.). This decreasing trend may be caused by the swelling up of the kernel as the moisture content of the seed increases, which makes the kernel inside the seed more susceptible to breakage when subjected to compressive force. However, the percentage of partially shelled seed and unshelled seed after shelling increases linearly with the increase in the moisture content from 8.00% to 13.68% (w.b.). The information obtained for all of the aforementioned parameters is more extensive than that reported by Ting et al. (2012).

Effects of moisture content variation on shelling efficiency

The effects of moisture content on the shelling efficiency of the jatropha-seed-shelling machine are shown in Table 2. It was observed that the shelling efficiency increased linearly from 73.95% to 79.73% when the moisture content of the jatropha seed was increased from 8.00% to 13.68% w.b., which contradicts the trend obtained for decortications efficiency as reported by Pradhan et al. (2010). However, the values obtained for shelling efficiency are similar to those obtained by other researchers. The higher the moisture content, the more brittle the seeds are, and hence the kernels are more easily detached. Figure 4 shows the relationship between jatropha seed moisture content and shelling efficiency.

Effects of moisture content variation on machine efficiency

The effects of moisture content variation on machine efficiency are shown in Table 2. It was observed that an increase in seed moisture content resulted in a decrease in the efficiency of the machine. At an initial moisture content of 8.00% w.b., the efficiency of the machine was found to have a maximum value of 31.52%, and at a moisture content of 12.21% w.b., the machine efficiency was the least at 26.57%. The efficiency of the machine decreases because at high moisture content, the seed shells were sticky, resulting in the need for a high friction force to separate the shell from seeds. However, at lower moisture content, the seeds were less sticky and required less force to split and therefore separated much more easily.

Table 2. Effects of moisture content on some machine operation parameters

Moisture content (% w.b.)	Machine capacity (Kg/h)	Shelling efficiency (%)	Machine efficiency (%)
8.00	48.13	73.95	31.52
9.37	48.76	74.84	29.97
10.77	44.37	79.71	30.61
12.21	47.28	78.45	26.57
13.68	43.69	79.73	30.39

Conclusion

The investigation and performance evaluation of a machine for shelling of *Jatropha curcas* seeds showed the following:

(1) The machine capacity was found to have a minimum value of 43.69 kg/h at a moisture content of 13.68% and a maximum value of 48.76 kg/h at moisture content 9.37%.
(2) The shelling efficiency was found to have a minimum value of 73.95% at moisture content of 8.00% and a maximum value of 79.73% at moisture content of 13.68%.
(3) The percentage of whole kernel recovered was found to have a minimum value of 17.23% at moisture content of 12.21% and a maximum value of 23.23% at moisture content of 8.00%.
(4) The percentage of broken kernel recovered was found to have a minimum value of 29.92% at moisture content of 9.37% and a maximum value of 33.65% at moisture content of 12.21%.
(5) The percentage of unshelled seed recovered was found to have a minimum value of 12.34% at moisture content of 10.77% and a maximum value of 15.29% at moisture content of 8.00%.
(6) The overall machine efficiency was found to have a minimum value of 26.57% at moisture content of 12.21% and a maximum value of 31.52% at moisture content of 8.00%.

Conflict of Interest

The authors have no conflicting financial or other interests.

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