# Development a Juice Extractor for *Spondias Mombin* Fruits

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***Abstract*—A juice extractor for Spondias mombin operating on co- axial screw press principle was designed constructed and evaluated in this study. The design principle adopted was borrowed from that of the digestion and screw pressing of palm fruit. The juice extractor was designed and fabricated based on the data obtained on the properties of the fruit. The performance of the machine was carried out using a 3x3x2 factorial experimental design with shaft speed (120, 130 and 150 rpm), loading (5, 10, and 15 kg) and ripeness (about to ripe and ripe) as factors. Data collected include throughput capacity, quantity of juice and extraction efficiency. Increase in shaft speed and loading increased the throughput of the machine with the values for ripe fruit highest. The quantity of juice extracted and extraction efficiency of the machine increased with increase in loading and degree of ripeness. However increase in speed from 120 to 130 rpm increased the quantity of juice and extraction efficiency but the two parameters dropped as the speed was increased to 150 rpm. The highest throughput and extraction efficiency which were 100 kg/h and 94.3%, respectively were recorded at sample with 5 kg loading, speed of 130 rpm and ripe condition.**

***Keywords—Extractor, Screw press, Efficiency, Throughput capacity***

## 1. INTRODUCTION

Hog plum (*Spondias mombin*) is a tree, in the *Anacardiaceae* family. It is native to the tropical Americas, including the West Indies. The tree has been naturalized in Africa, India and Indonesia where it is mostly grown as an orchard tree. It is well adapted to arid as well as humid zones (Aiyeloja and Opeyemi, 2006). In Africa the tree is commonly planted as a living fence. *Spondias mombin* fruits (Plate 1.2) are mainly eaten fresh, but sometimes are harvested green and eaten with salt as a snack. In Mexico, the ripe fruits are sometimes boiled in water with or without salt and only eaten dried afterwards. In Florida, the dried slices or the ripe fruits have been occasionally commercialized (Dias *et al.,* 2003). The soft exocarp is easily injured and so the mesocarp is processed into "marmalade", juice, wine and liquor. The pulp is used as a flavoring for ice cream. The root part of the tree is used for emergency water source; the stem part is used for home fence in farm land. The tree is used as shelter by artisans because it has a low quantity of wood. The wood gum is used for match sticks, match boxes, physician spatulas, stick for sweet, meat, pencil, pen holder, racking cases etc while the wood ashes is also used as indigo dye. The bark is used in carving figures like amulet, statuettes cigarette holder and various ornamental objects and dyeing agent (Ayoka *et al.,* 2008).

*Spondias mombin* has a good calorific density due to the high concentration of total carbohydrate (13.1%). Fructose, glucose and sucrose together account for 65% of the total soluble solids. It is a moderate source of potassium and starch and a good source of Vitamin C (Koziol and Macia., 1998). The main flavour compound is 2-hexenal. Ayoka *et al.* (2008) reported that morphological acts of *Spondias mombin* tree have high medical value. The fruits decoction is drunk as a diuretic and febrifuge while the decoction of the bark and leaves is used as emetic, anti-diarrhea and dysentery treatment. The antimicrobial, antifungal and the antiviral properties of *Spondias mombin* have been reported (Ajaoand Shonukan, 1985; Abo *et al.,* 1999; Corthout *et al.,* 1991).

Substantial quantities of *Spondias mombin* get wasted during its peak season due to lack of appropriate processing techniques and preservation methods. The fruits are eaten raw and those that cannot be eaten are discarded due to spoilage. This results in serious economic loss. A machine capable of extracting juice from the fruit was developed in this study.

## 2. MATERIAL AND METHODS

### 2.1 Design of the Components of the Machine

It was considered that the machine should be able to process about 15 kg of fruit at a batch and that the machine consists of a horizontal digester which operates at 220 rpm from the work of Owolarafe *et al., 2001*). and screw press which has the maximum speed of 110 rpm. A speed of 150 rpm was used since the digester and press units of the extractor are coaxial. Most of the parts of the extractor were constructed with stainless sheet to avoid rusting and contamination.

The machine consists of a hopper, the maceration section, the digestial unit, the barrel and the discharge chutes for juice and the pulp.

The hopper was designed to take about 15 kg of the *Spondias mombin* fruit per batch. The shape of the hopper as portray by the dimension in Figure. 1 was chosen to ensure free flow of fruit under gravity. This was done by taking into consideration the angle of repose of the fruit. The dynamic angle of repose from experiment was determined to be 28.5$^o$. For the purpose of designing and fabrication of the hopper 17.7$^o$ was taken as the angle of friction (Owolarafe *et al*., 2006)

The calculation for the dimension of the .hopper is presented below:

Mass of the fruit per batch of operation (M) =15 kg

Density of fruit (ρ) = 616.5 kg/m$^3$ (Owolarafe *et al.,* 2006)

Porosity of the fruit = 20.7% = 0.207

Angle of friction of fruit = 17.7$^0$ Volume of fruit (V) = M/ρ=15/616

=2.44 x10 $^{-2}$ m$^3$

The height of hopper is calculated thus:-

tan 17.7$^o$ = $h_1$/150

$h_1$ = 150 tan 17.7$^o$

$h_1$ = 47.87 mm

Capacity of the hopper = 1/3 x base area x height.

= 1/3 x 0.125 x 0.125 x 0.04787

= 2.49 x 10$^{-4}$ m$^3$.

The handling capacity of the hopper is 2.49 x 10$^{-4}$ m$^3$

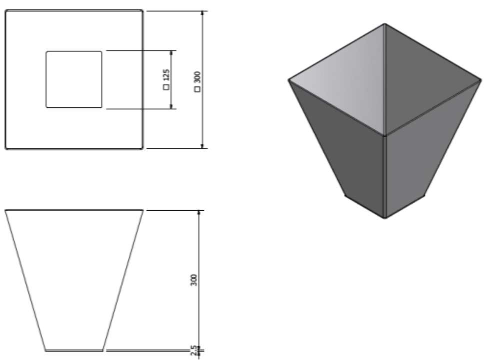


Fig 1: Orthographic and Isometric views of the hopper

The macerator section (Fig. 2) is a 480 mm × Ø200 mm × 3 mm stainless steel pipe. It consists of a shaft 75 mm with arms (rod) welded to the shaft to a length of 633 mm, from one end of the shaft. The digester macerates the fruit and at the same time conveys the mash to the extraction chamber. It has a capacity of 15 kg fruits. The processing of the fruit starts from the macerator to the extracted chamber and ends at both juice and pulp outlets.

This was designed on the basis of internal pressure only. Using the standard stress analysis techniques applied to thick well pressure vessel (Sivakumaran and Goodrum, 1987). The tangential stress,α perpendicular to the axis of the barrel was as stated below

$$\alpha = \frac{2PD^2}{d_{out}^2 - d_{in}^2}$$ (Khurmi and Gupta, 2006).1

Where α = perpendicular stress which was the maximum tensile stress that the barrel would be subjected to at failure by yield.

P = internal pressure

$d_{in}$ = internal diameter of the barrel

$d_{out}$ = out diameter of the barrel.

For mild steel, the ultimate or yield stress = 140 MN/m$^2$

P = 1.375 N/m$^2$ (from experiment, the minimum value of compressive stress)

$_{din}$ =0.18 m = 180 mm

Therefore,

$$140 \times 10^6 = \frac{2 \times 1.375 \times 0.18^2}{d_{out}^2 - 0.18^2}$$

$d_{out}^2$ = 181mm

The screw press consists of Ø50 mm × 633 mm spiral worm shaft. At one end of the screw press shaft is a conical frustum with an angle of 60$^0$ with a length of 100 mm and width of 105 mm (Fig 2).

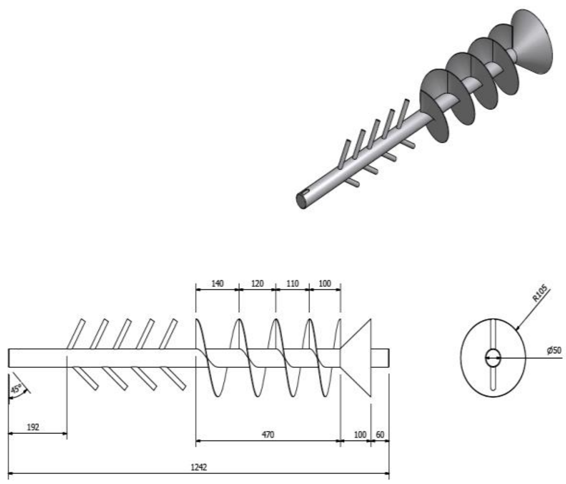


Fig 2: Maceration and screw auger

The cylindrical barrel consists of both the upper and lower halves (Figs 3 and 4) which are connected together by a flange bolted by 32.5 mm bolts and nuts. It is constructed from stainless material of diameter 200 mm. The barrel is designed for both digester and screw section of the shaft. As shown in

Fig 3, the upper barrel has a square opening of 125 mm where hopper is inserted into the upper barrel

The discharge chutes (juice and pulp collectors) are made up of stainless steel material. The juice collector is made up of 50 mm diameter pipe welded to the lower barrel while the pulp collector with 3 mm thickness is welded to the frame of the right hand side of the machine. It is made in the form of a prism having frustum cross – section so as to fit within the space of the machine frame.

The frame is made up of angle iron of 50 x 100 x 50 mm in cross- section. The frame is 1096 mm long, 335 mm wide and 600 mm in height. Other parts of the machine as such as electric –motor, hopper assembly, the shaft, barrel, bearing, pulley and V-belt were mounted on the frame.

### 2.2 Power Requirement of the Machine

The power required P, can be divided into three parts: (Audu*et al*., 2004)):

Power required for extraction, $p_h$

Power required to drive screw shaft, $P_c$

Power required to drive the pulley, $P_p$

The power required for extraction was obtained from the following equations

$$p_h = T\omega \quad (1)$$

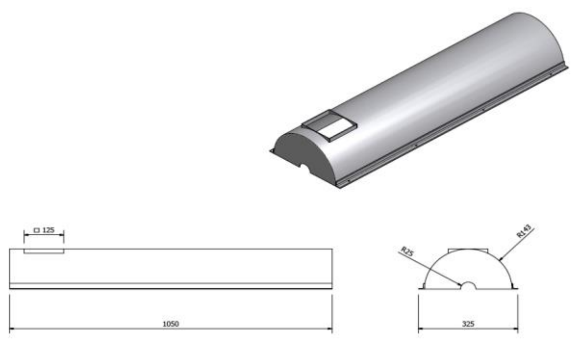



Fig 3: The upper barrel

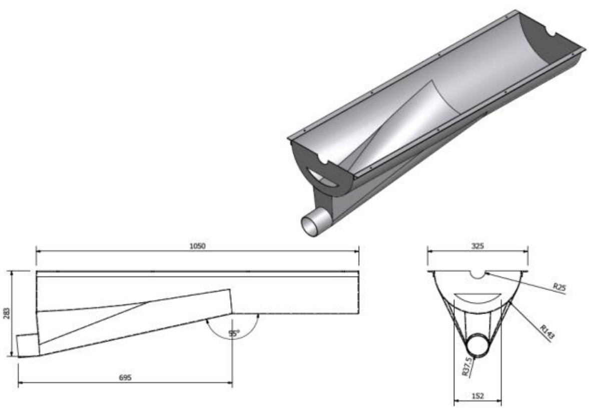



Fig 4: The lower barrel

$$T = \frac{\pi t D^3}{16}$$ (Oyinlola*et al.,* 2004) (2)

Substituting for the value T becomes,

$$T = \frac{3.143 \times 1.375 \times 0.325^2}{16}$$

$T = 2.853 \times 10^{-2}$ Nm

From the compression stress experiment result, the shear stress = 1.375N/mm$^2$

$$\omega = \frac{2\pi N}{60} \quad (3)$$

Substituting for the value ω becomes

$$\omega = \frac{2 \times 3.143 \times 150}{60}$$

= 15.72

$P_h = 2.853 \times 10^{-2} \times 15.72 = 0.449$ W

Using the above equation, and for screw speed of 150 rpm, $P_h$was found to be 0.449 W

To obtain the power required to drive the screw shaft, $P_c$, torque was first obtained using Equation 4

$T = W_cR$ . . 3

Where,

$W_c$= weight of screw shaft (N).

$W_c$= 29.688 kg (from Appendix ll)

R = radius of shaft which is 50 mm

Substituting for the value of W and R and becomes

= 29.688 x 0.05

=1.48 W

$P_c = T\omega$

$P_c = 1.4844 \times 15.72 = 23.33$

To drive the pulley, the power required Pp was estimated to be 111.92 W (Oloso, 1988)

The total power P was then found as:

$P = P_h + P_P + P_C = 0.449 + 23.34 + 111.92$

P = 135.70W = 0.136 kW

### 2.3 Determination of Shaft Diameter

Using a power source of 3.5 kW as the prime mover for the machine, the torsional moment ($M_t$) due to the applied load can be determined (Hall *et al.,* 1980):

$$M_t = \frac{9550 \times KW}{\frac{Rev}{min}} \quad (4)$$

Given that power = 3.5 kW and Speed = 150 rpm

$$M_t = \frac{9550 \times 3.5}{150} \text{ Nm} = 222.83 \text{ Nm}$$

Using the bending moment diagram in Appendix 1, the maximum bending moment ($M_b$) was found.

$M_b$ = 34.2104 Nm

The diameter of the shaft was then determined using equation below:

$$d^3 = \frac{16}{\pi s\sqrt{kMb}^2 + (K_t M_t)^2}$$ (Hall *et al.*, 1980) (5)

Ultimate strength = 140 MN/m$^2$

Where $S_s$ = 55 MN/m$^2$ (using a factor safety of 2.5)

$K_b$ = 1.5

$M_b$ =34.2104 Nm

$K_t$ = 1

$M_t$ = 145.33 Nm

$d^{\uparrow}3 = 16/(\pi \times 56 \times [10]^{\uparrow}6)\sqrt{(([(1.5 \times 34.2104)]^{\uparrow}(2)) + [(1 \times 145.33)]^{\uparrow}2})$

$= 1.401688 \times 10^{-5}$

$d = 24.11mm$

**2.4 Determination of the Screw Pitch**

The pitch of the screw thread was determined by considering the handling capacity of the screw press and the difference between the volumes of the untapered and the tapered end of the extraction section (Figure 5)

$V_{H=}(V_{U-} V_T)$ P (6)

Where

P = pitch of screw thread.

$V_H$ = handing capacity of the screw press

$V_U$ = capacity of the untapered end of the cone

$V_T$ = capacity of the tapered end of the cone.

. (i) The screw thread length = 0.4684 m

(ii) The desire range of speed for the screw press was 30 to 60

revolution per minute (rpm).

(iii) An integral cone of 40 mm inner diameter, 150 mm outer and 120 mm

length was incorporated in the press.

(iv) In one revolution of the screw, the output was advanced by one pitch of th thread.

(v) The handling (design) capacity of the screw press as obtained from

Equation 3.20 was given as 8.64x10$^{-4}$ m$^3$

Using equation 3.19, the pitch of the thread was calculated thus:

$V_H$=8.64x10x10$^{-4}$ m$^3$

$$V_{U=}\frac{\pi(0.12)^p}{4} \quad (7)$$

= 11.31x10$^{-3}$Pm$^3$

$$V_{T=}\frac{\pi(0.04)^p}{4}$$

=1.32x10$^{-3}$P m$^3$

Hence, 8.64x10$^{-4}$ m$^3$ = (11.31-1.32) x 10$^{-3}$P m$^3$

$$P=\frac{8.64 \times 10^{-4}}{(11.31 - 1.32) \times 10^{-3}}$$

P =0.0864 m

P=86 mm

Efficiency of machine= $\frac{Mechanical\ advantage \times 100\ \%}{Velocity\ ratio}$ (8)

Velocity ratio = $\frac{2\pi \times distance\ moved\ by\ effort}{pitch}$ (9)

From equation 8, efficiency of the machine can Increased by a decreased in the velocity ratio. This could be achieved by an increase in the pitch (equation 6). This implied that the pitch length could be increased as from 90 mm. pitch lengths of 90 mm. 100 mm; 110 mm and 120 mm were selected.

The number of thread (n) = $\frac{Length\ of\ screw\ thread}{pitch}$ (10)

Equation 10 is used to calculate the number of thread if the length is constant.

**2.5 Fabrication and Assembly of the Machine Components**

Figs. 5 and 6 show the orthographic and schematic view of the extractor while Plate1 shows exploded view of the juice extractor for *Spondiasmombin* fruits. Assemblage of the machine began with the welding of the frames, the hopper and the electric motor seat. The upper and lower parts of the barrel were also bolted to the frame

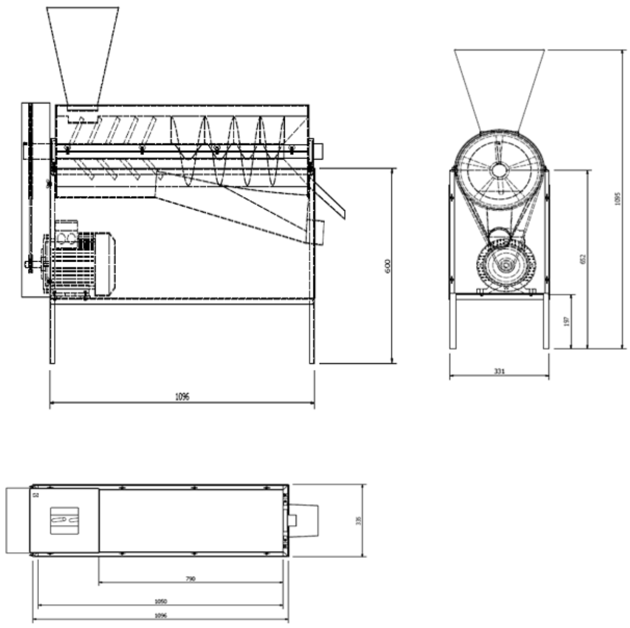
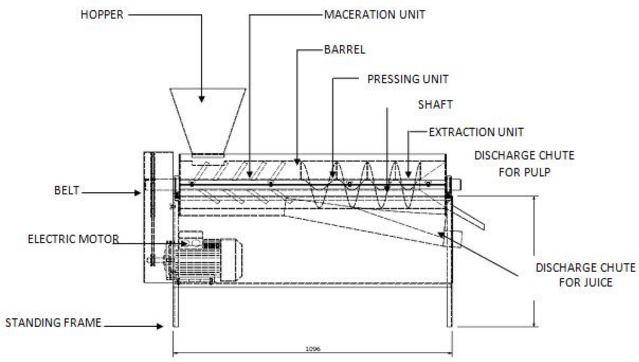
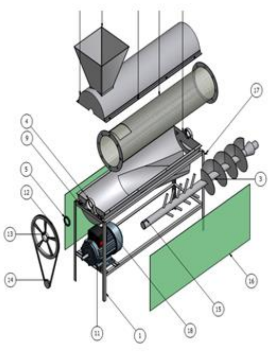



Fig 5. Orthographic drawing of *Spondiasmombin* juice extractor



| ITEM | PART NUMBER | QTY | MATERIAL |
|---|---|---|---|
| 1 | Frame | 1 | |
| 2 | Lower Chamber | 1 | Stainless Steel |
| 3 | Auger | 1 | Stainless Steel |
| 4 | Bearing house | 2 | Steel |
| 5 | Rolling bearing 71810 C GB/T 292-94 | 2 | Steel, Mild |
| 6 | Screen | 1 | Stainless Steel |
| 7 | Upper Chamber | 1 | Stainless Steel |
| 8 | Hopper | 1 | Stainless Steel |
| 9 | ISO Washer 7089 - 5 - 140 HV | 40 | Stainless Steel |
| 10 | ISO Bolt 4033 - M5 | 12 | Steel |
| 11 | AC Motor | 1 | |
| 12 | V-Belt | 1 | Rubber |
| 13 | Grooved Pulley1 | 1 | Steel |
| 14 | Grooved Pulley2 | 1 | Steel |
| 15 | ISO Keyway 2491 - A 14 x 6 x 40 | 1 | Steel, Mild |
| 16 | Frame Cover | 2 | Steel, Mild |
| 17 | Discharge Plate | 1 | Stainless Steel |
| 18 | Brace Plate | 4 | Steel, Mild |

Plate 1: Exploded view of the juice extractor

### 2.6 Performance Evaluation of the Machine

Fresh *Spondiasmombin* fruits were harvested from Obafemi Awolowo University. The fruits were detached and the good fruits sorted into sizes, ripeness and washed with running water. The machine was evaluated using a variable speed reduction geared- electric motor with a rated speed of 230 rpm . The speed was further reduced between 120-150 rpm by a belt and pulley system. The speeds were later confirmed with a portable tachometer. Between fifteen and five kilograms of the fruit samples was weighed on a weighing balance and fed into hopper


Plate 2: Pictorial view of the machine during performance evaluation

per batch. Three parameters were varied in carrying out the evaluation. These were degree of ripeness, the shaft speed and the feeding rate. Data determined include juice yield in volume, throughput capacity of the machine and quality analysis.

The yield of juice in percentage was calculated as follows:-

$$y_{juic} = \frac{Q_j}{Q_f} \quad (11)$$

Where

Qj = quantity of juice in kg

$Q_f$ = quantity of fruit processed in kg. (Quantity of juice extracted and the residue in kg)

The capacity of the machine was calculated as shown below.

$$\text{Capacity of machine } (Cap_m) = \frac{Q_f}{T} \quad (12)$$

Where

$Q_f$ = Quantity of fruit processed in kg

T = Time taken in minute

Extraction efficiency ($E_E$) in percentage is the ratio of the weight of juice extracted to the product of the juice content (moisture content) of the fruit and the weight of the product before extraction.

$$E_E = \frac{Q_j \times 100}{XQ_f} \quad \text{(Olaoye. and Oyelade, 2012) (13)}$$

Where $Q_j$ is quantity of juice extracted in kg

X is the juice content (moisture content juice) in %

$Q_f$ is the quantity of fruit processed in kg.

## 4. RESULTS AND DISCUSSION

The result of the throughput capacity and quantity of the juice extracted using the machine are discussed below. The effect of processing condition on the throughput of the machine is discussed in terms of shaft speed , degree of ripeness, and loading.

### 4.1 Effect of Processing Factors on the Throughput of the Machine

The throughput capacity of the machine was observed to increase with increase in shaft speed from 120 rpm to 150 rpm for both about to ripe and ripe fruits (Table 1). This expectedly may be attributed to reduction in residence time of the processed fruit in the machine leading to more materials being processed. This result is similar to result obtained by Harmanto *et al.* (2009) on jatropha curcas seed.

Generally the throughput capacity of the machine was observed to increase with degree of ripeness. For example at 130 rpm shaft speed and loading of 5, 10 and 15 kg, the throughput capacity increased from 49.8 to 75.0, 63.0 to 75.0 and 60.0 to 69.0 kg/h, respectively. The increase in throughput capacity of the machine with increase in degree of ripeness can be attributed to the fact that the more the fruit is ripe the softer the mesocarp and the easier the digestion and hence the better flow to allow more material into the maceration and pressing units. This report is similar to the findings of Owolarafe *et al.* (2001) on the digestion of palm fruit and expression of the oil using digester-screw press. Statistical analysis of the effect of ripenesss on the the throughput capacity of the machine indicated that the effect was significant ($p < 0.05$).

**Table 1: Effect of Processing Condition on the Throughput Capacity of the Machine**

| Speed (rpm) | Feeding (kg) | Throughput capacity (kg/h) | |
|---|---|---|---|
| | | About to ripe | Ripe |
| 120 | 5 | 42.6 | 60.0 |
| | 10 | 54.6 | 54.6 |
| | 15 | 52.8 | 56.4 |
| 130 | 5 | 49.8 | 75.0 |
| | 10 | 63.0 | 75.0 |
| | 15 | 60.0 | 69.0 |
| 150 | 5 | 85.8 | 100.0 |
| | 10 | 75.0 | 85.8 |
| | 15 | 75.0 | 90.0 |

### 4.2 Effect of Processing Conditions on the Quantity of Juice Extracted

Table 2shows the relationship between the loading and quantity of juice in kilogram extracted at the three levels of speed and the two ripeness conditions. It could be observed that increase in loading condition increased the quantity of juice extracted. Increase in yield of juice with increase in loading rate may be attributed to more material available for processing. Also the quantity of juice could be observed to also increase with increase in degress of ripeness which may be attributed to better digestion as a result of softness of the material and hence more fluid expressed during pressing.The volume of juice extracted could however be observed to first increase with increase in speed from 120 to130 rpm at loading rates and levels of ripeness and then decreased with increase in speed from 130 to 150 rpm. The increase in the volume of juice at the first instance may be attributed to better digestion with increase in shear force hence allowing more of the fluid to be mobilised into the interkernel void. The subsequent reduction could be due to reduction in residence time in the pressing unit. Similar results were obtained by Harmanto *et al*.(2009) in extraction of Jatropha curcas seed oil using screw-press.

### 4.3 Effect of Processing Conditions on the Extraction Efficiency of the Machine.

Table 3shows the extraction efficiencies of the machine at the different processing conditions. It could be observed that the efficiency increased with increase in speed from 120 to 130 rpm and later decreased as the speed was increased from 130 to 150 rpm at the two conditions of ripeness. This could be explained that there was adequate digestion of the materials with increase in speed in the first instance leading to more juice being extracted while the reduction in the efficiency as the speed was further increased may be attributed to reduction in residense time. It could also be observed that increase in loading from 5 to 10 kg initially increased the efficiency of the machine while further increase in

**Table 2: Effect of Processing Condition on the Juice Quantity Extracted.**

| Speed (rpm) | Feeding (kg) | Quantity of Juice Extracted (kg) | |
|---|---|---|---|
| | | About to ripe | Ripe |
| 120 | 5 | 1.5 | 1.8 |
| | 10 | 3.5 | 3.9 |
| | 15 | 4.3 | 5.3 |
| 130 | 5 | 2.0 | 2.2 |
| | 10 | 3.8 | 4.1 |
| | 15 | 4.6 | 5.6 |
| 150 | 5 | 1.8 | 1.4 |
| | 10 | 3.5 | 3.0 |
| | 15 | 4.3 | 4.2 |

**Table 3: Effect of Processing Condition on the Juice extraction efficiency of the machine.**

| Speed (rpm) | Feeding (kg) | Extraction efficiency of machine (%) | |
|---|---|---|---|
| | | About to ripe | Ripe |
| 120 | 5 | 64.31 | 77.17 |
| | 10 | 75.02 | 83.60 |
| | 15 | 61.45 | 75.74 |
| 130 | 5 | 85.75 | 94.32 |
| | 10 | 81.46 | 87.89 |
| | 15 | 65.74 | 80.00 |
| 150 | 5 | 77.17 | 60.02 |
| | 10 | 75.02 | 64.31 |
| | 15 | 61.45 | 60.02 |

loading to 15 kg reduced the efficiency of the machine. The first increase in extraction efficiency may be due to more fruit available for processing and hence more juice yield while the subsequent reduction in extraction efficierncy may be attributed to plugging at the pressing unit leading to low juice yield. At all the speeds of 120 and 130 rpm and loading levels, increase in ripeness condition was observed to increase the extraction efficiency while there was reduction in the efficiency in the case of the 150 rpm. The reason for this may be attributed to formation of slurry at that speed hence reducing the juice yield. Similar results were obtained by Harmanto *et al*.(2009) in extraction of Jatropha curcas seed oil using screw-press

## 5. Conclusion

A juice extractor for *spondiasmombin* fruit was designed in this study. The extractor was evaluated for its performance in terms of throughput, quantity of juice and extractor efficiency. The throughput capacity of the machine increased with increase in shaft speed. It varied from 42.6 kg/h to 100 kg/h at various shaft speeds and loading. At the three levels of speed and two ripeness conditions increase in loading condition increased the quantity of juice extracted. The quantity of juice extracted increased with increase in degree of ripeness (i.e. from unripe to ripe) fruit. The highest throughput and extraction efficiency were find to be 100 kg/h and 94.32% respectively for ripe fruits.

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