NIGERIAN AGRICULTURAL JOURNAL
ISSN: 0300-368X
Volume 51 Number 3, December 2020 Pg. 254-263
Available online at: http://www.ajol.info/index.php/naj

DEVELOPMENT OF A GROUND-BREAKING MULTI-JUICE EXTRACTION MACHINE

Kadurumba, C.H. and Ogundu, M. I.

Michael Okpara University of Agriculture Umudike and
National Root Crops Research Institute Umudike,
Corresponding Authors' email: kaduruchuma@gmail.com

Abstract
This study centers on the design, development and performance evaluation of a juice extractor developed using locally-available materials. The machine designed was simple, compact and portable. The size makes it suitable for household use. The uniqueness of the machine is centered on its ease to assemble and disassemble. The machine is made up mainly of two units: Power end and Extraction. The power end is where the motor which transmits power to the shaft is located. The auger shaft which is the main component of the extraction unit conveys the fruits and squeezes it against the walls of the barrel of the cone shaped end. The motor transmits enough power to masticate the fruit that is fed in through the hopper and relatively rotates at a slow speed to achieve proper squeezing. The fresh orange, pineapple and water melon fruits were tested. Result shows that the average juice yield for orange, pineapple and water melon was 76.5%, 82.0% and 91.9% respectively; juice extraction efficiencies was 91.9%, 94.5% and 96.7%; and juice extraction losses 6.3%, 6.9% and 4.2% also. The extractor is powered by a 1hp electric motor. The machine has a capacity to process 0.028m^3/hr of oranges, 0.03m^3/hr of pineapples and 0.031m^3/hr of water melon and cost of machine ₦64,000. Hence, the machine is affordable and it is recommended for small and medium holder juice processors.

Keywords: Multi-juice extractor, Inlet velocity, Screw conveyor, Pineapple, and Water melon

Introduction

Fruits are used to complement nutritional requirement that maybe lacking in staple food since it contains adequate amount of water, sugars, vitamins and dietary fibers (Aviara *et al.,* 2013). Fruits are susceptible to spoilage due to their high moisture content and losses due to postharvest spoilage in these products can occur through infections that occur in the field, during harvest, storage or distribution. Post-harvest losses in fruits have been reported to be 20 – 50% in developing countries (Muhammad *et al.,* 2012). This result agrees with the study carried out by Ndubisi *et al.* (2013) on fruits which indicated that the losses were up to 30% during the rainy season. This problem leads to scarcity and high cost of fresh fruits during the off-season. These losses can be averted if early processing of these products can be carried out. Lack of low cost and efficient means of processing the product, poor marketing and transport system and fruit perishability contribute to more post-harvest losses. Lack of local and simple mechanical means for fruit processing into juice often results in limitation on fruit utilization and thus more post-harvest losses due to rots. Juice extraction is the process of squeezing the liquid content out of fresh fruits. It involves the process of crushing, squeezing and pressing of whole fruit in order to obtain the juice and reduce the size of the fruit to liquid and pulp (Adewumi and Ukwenya, 2012). It is essential to process the freshly harvested fruit into juice which can be consumed fresh or processed further into healthy beverages (Badmus and Adeyemi, 2004). Orange fruit with a density of about 734 kg/m3 is a rich source of vitamin- C and should be processed into juice or fragrant peel (Olaniyan, 2010). He designed and constructed a small scale orange juice extractor using locally available construction materials. The machine results showed that the average juice yield and juice extraction efficiency were 41.6 and 57.4%, respectively. The machine was powered by a 2hp electric motor, with a capacity of 14kg/h and cost of about N45,000. Adewumi and Ukwenya (2012) designed and fabricated an extractor for the juice and pulp of mango fruit. The machine juice extraction efficiency of 76% was recorded. The extractor requires a power of 1.42hp, and the production cost of the extractor is N48, 000. Also, the thorough-put value of 14.36g/s was recorded for the machine. Olabisi and Adelegan (2015) designed and constructed a citrus juice extractor made up of a hopper, a cylindrical main housing, a screw press, and a perforated screen an outlet. The shaft was constructed using stainless steel. It has an extraction efficiency of 84%, 87% and 89% for orange, tangerine and lime respectively. The machine was allowed to run for six hours per day and was able to extract juice from an average of 3.36, 10.85 and 10.47tonnes of orange, tangerine and lime respectively. Eyeowa *et al*. (2017) developed a manually operated juice extractor using locally sourced materials. It consists of a feeding unit, extraction unit, juice collector, waste outlet, frame and bearings. The efficiencies obtained were 57%, 53.6% and 52.9% for water melon, tangerine and pineapple respectively. The extraction efficiencies for water melon, orange and pineapple was 71.3%, 65.8% and 63.8% respectively. The extraction losses for water melon, orange and pineapple was 2.5%, 4.3% and 3.5% respectively. In order to reduce extraction losses and improve extraction efficiencies of the existing juice extraction machines this study designed, simulated, developed and carried out a performance evaluation of the innovative juice extractor.

Materials and Methods

Description of the Motorized Juice Extractor

The juice extractor has four major sections which are the power end, fruit inlet, extraction chamber, and juice outlet. The power end consists of the electric motor and the motor casing. The fruit inlet consists of the feeding hopper. The extraction chamber consists of the screw conveyor, and cylindrical barrel with a conical end. The juice outlet consists of the sieve and juice nozzle. Plate 1 shows the the ground-breaking juice extractor.

Plate 1 *Multi*-Juice Extractor

The machine size makes it suitable for household use. It could be used in hospitals, schools, hotels, eateries and any other place of interest. The uniqueness of the machine is in its ease of maintenance. The screw conveyor is coupled directly to the electric motor and the cylindrical barrel bolted to the motor casing by means of bolts. The feeding hopper has a threaded end by which it was screwed to the cylindrical barrel. The juice extractor works on the principle of crushing and squeezing (masticating). The motor transmits the required power to masticate the fruit that is fed in through the feeding hopper and relatively rotates at a slow speed to achieve proper squeezing. The hopper is located directly above the auger which has a reducing pitch. The pitch size provides a sizeable quantity of fruits to be conveyed with one pitch revolution. The extraction chamber is made up mainly of the auger shaft and the cylindrical barrel with cone-shaped masticating end. The auger shaft moves the fruit against the cone-shaped end as the base of the cone reduces. The juice is forced out and rolls down the cone-shaped end and flows until it gets to the juice outlet. As this occurs, the pulp is forced out through the cone-shaped end. The flow chart simplifies the operational sequence of the designed juice extractor.

Design of the innovative Juice extractor

Volume of the hopper

The hopper has the shape of a frustum in order to accommodate enough fruits and vegetables. The fruits are introduced into the hopper by gravity and to the extracting compartments. The volume of hopper was calculated thus;

$$V = \frac{1}{3}\pi({r_1}^2 + r_1 r_2 + {r_2}^2)h \qquad \text{………..(1)}$$

Where V is the volume of the hopper, r_1 = 160mm as the upper radius of the hopper, r_2 = 120mm as the lower radius of the hopper and h = 300mm as height of hopper. The volume of the hopper was chosen not to exceed the quantity of fruit the machine would process at a time.

Diameter of the Shaft

The screw conveyor is the main component of the extraction unit and its shaft is acted upon by weights of the pulley and screw thread. In operation, the screw conveyor conveys, crushes, presses and squeezes the chopped fruit lumps for juice extraction. Therefore, to safeguard the shaft against bending and torsional stresses, the diameter of the shaft was determined following Khurmi and Gupta, (2008) thus;

$$d^3 = \frac{16}{\pi\tau}\sqrt{(k_b M)^2 + (k_t T^2)} \qquad \text{…….. (2)}$$

Where; d is the diameter of auger shaft in m, τ = allowable shear stress ($55\text{x } 10^6 N/M^2$) for shaft without keyway, k_b = 1.5 is the combined shock and fatigue factor applied to bending moment, k_t = 1.0 is the combined shock and fatigue factor applied to torsional moment, M = 0.4440KNm is maximum bending moment, and T = 5.41Nm is maximum torsional moment. From equation 2, the ideal diameter was obtained to be 39.3mm and a shaft diameter of 40mm was selected to ensure satisfactory strength and rigidity during operation under loading conditions.

Design of Critical Speed of Shaft

The critical speed is the speed at which the rotating shaft becomes dynamically unstable. This causes vibration which is not required in the machine. The Critical speed of the shaft was determined by Rayleigh-Ritz equation given by Bhandari (2004) as stated in equation (3) thus;

$$N_c = \frac{\sqrt{\frac{g}{\delta}}}{2\pi} \;\ldots\ldots.. (3)$$

Where: N_c is Critical Speed in rpm, $g = 9.81\ N/m^2$ is the Acceleration due to gravity. The deflection $\delta = 2.45\text{x}10^{-6}$ is given in equation (4) thus;

$$\delta = \frac{5ql^4}{384EI} \;\ldots.. (4)$$

Where q = uniformly distributed load (N/m), l = 500mm is the length of the shaft, E = 200GPa is the modulus of elasticity and $I = 1.257\text{x}10^{-7}m^4$. Therefore from equation (3), the critical speed of the shaft is 318.5rpm.

Design of the load that can be lifted by the auger

The load to be lifted by the screw was determined in equation (5) following Hall *et al.* (2002).

$$W_e = T\,\frac{\frac{D_m}{2}\tan\theta + \frac{\mu}{\cos\alpha}}{(1-\mu\tan\theta\cos\alpha)} \quad \ldots. (5)$$

$$\alpha = \tan^{-1}(\tan\theta_n\cos\theta) \quad \ldots.. (6)$$

Where: W_e is Load that can be lifted by the screw in KN, T = 5.41Nm is the Torque transmitted by the screw shaft, D_m = 5mm is the Mean thread diameter, θ_n =15° is the Thread (lift) angle, $\mu = 0.58$ is the coefficient of friction, θ = 3° is the Tapering angle. From equations (6) and (5), α = 14.98° and W_e = 3.35N respectively. Therefore, 0.34kg of fruit could be processed at a time.

Design of the pressing area and pressure developed by the auger

The pressing area and the pressure developed by the auger were determined from equations (7) and (8) respectively following Hall *et al.* (2002) thus;

$$A_p = \pi D_m nh \;\ldots\ldots (7)$$

$$P_r = \frac{W_e}{A} \;\ldots\ldots.. (8)$$

Where; Pr is the Pressure developed by the auger, h = 4mm is the screw depth at the maximum pressure (discharged end); n = 7 is the number of threads. From equation (7), Ap = 439.8mm and a pressure of 0.01Mpa will be available for squeezing and pressing the fruits during operation.

Design of the pressure on the barrel

The pressure to be withstood by the barrel was determined from following Ryder (1985) thus;

$$P_b = \frac{2t\delta_a}{D} \;\ldots\ldots (9)$$

Where; Pb is the Pressure on the barrel, $_a$ = Allowable stress, and $_a$ = 0.27$_o$, $_o$ = 215Mpa is the yield stress of Stainless Steel, D_i = 69.5mm is the internal diameter of the barrel, t =1.2mm is the thickness of barrel. From equation (9), the pressure the barrel can withstand is Pb = 0.2MPa. This means that the pressure the barrel can withstand (0.2MPa) is greater than the pressure developed by the auger shaft. Therefore the barrel can withstand the extraction pressure without bursting.

Design of the first pitch of the decreasing pitch auger

Auger flighting design considerations and nomenclature are presented in EP389.1 (ASAE, 1993). This engineering practice states that the pitch of the flighting should be between 0.9 and 1.5 times the outside diameter of the flighting. Therefore, the first pitch of the decreasing pitch auger is given by equation (10), following ASAE (1993) thus;

$P_s = 1.4D_s \ldots\ldots (10)$

Where P_s and D_s is pitch and outside diameter of the auger respectively. Hence P_s = 56mm.

Design of the pitches of the decreasing pitch auger

The auger was designed to have pitches of decreasing order. In determination of the pitches, iteration method was used. A value was assumed for the first pitch (P(x)) in order to obtain a value for the inlet velocity (v), and then evaluate the remaining six pitches using iteration. The summation of the seven pitches must not be greater than the total length of the auger (0.50m). The auger was designed using a method by Jones and Kisher (1995) cited in Gbabo *et al.* (2013) thus;

$$P_m = \frac{P_t}{\eta} \;\ldots.. (15)$$

Where: P_m is the power of the prime mover, ή = 75% or 0.75 is the drive efficiency, and P_t = 0.74 is the power requirement of the machine. Therefore, from equation (15), a 1hp motor would be required to drive the machine.

Orthographic drawing of the Extractor

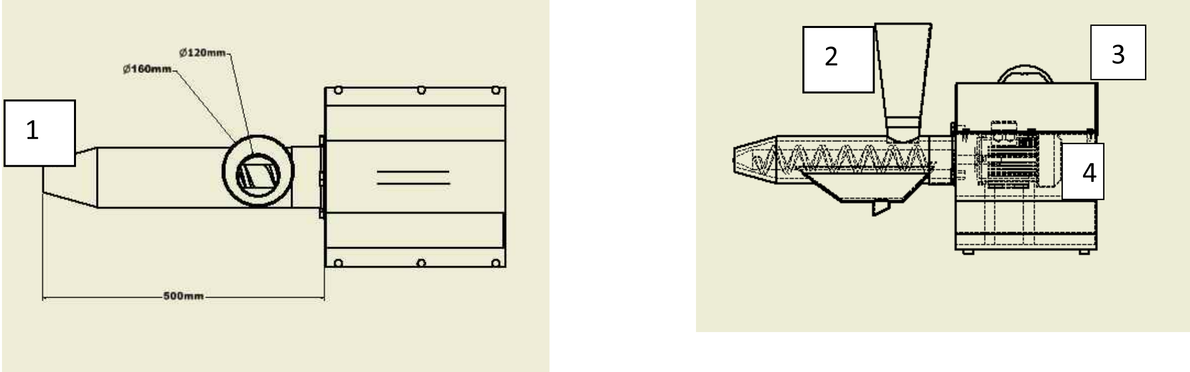

Figure 1 orthographic drawing showing the hopper and the motor

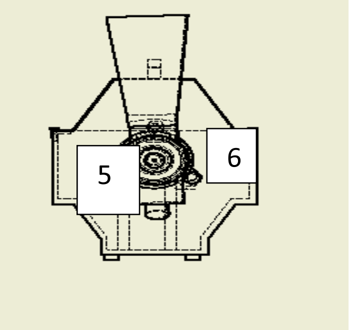

Figure 1: Multi-juice extractor in orthographic views; (1) Extraction chamber, (2) Hopper (3)Tool frame (4) Electric motor, (5) Screw conveyor, (6) Juice Drain

Simulation

The Simulation of the machine was done to understand how the machine will behave when developed and particular attention was paid to the design analysis. The parameters used during the simulation process were developed after the design analysis and the simulation was done using Autodesk Inventor.

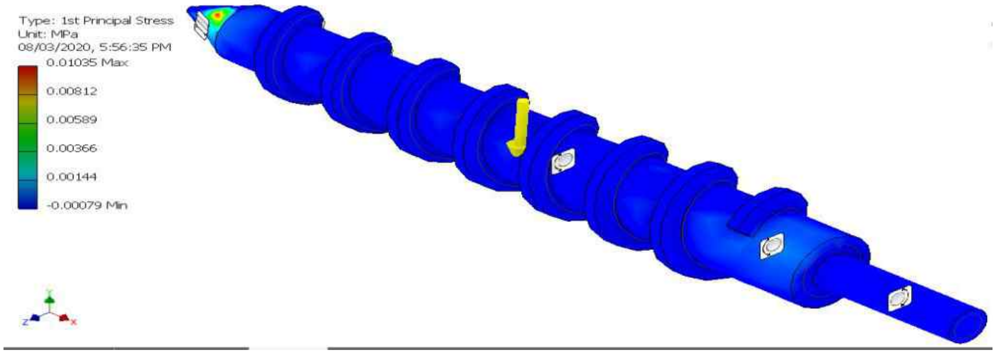

Figure 2: Simulation of the Shaft

From the First principal stress analysis as shown in Fig. 2, the major stress concentration point on the shaft is the pressing area and the stress value around that point is about 0.01Mpa. This conforms to the design analysis made and shows that the shaft will not fail. Also the maximum stress on the barrel is 0.2Mpa, and this also shows that the barrel can withstand the pressure developed by the auger shaft.

Material selection and Fabrication Processes

The design specification gives particular and quantitative information about the machine to be constructed and takes certain factors such as ease of fabrication into consideration. In this study, the machine fabrication was done with the use of available tools, machines and technology. The materials were selected based on rigidity, corrosion resistance, non-reactivity to the juice to be extracted, cost effectiveness, ease of fabrication and availability of equipment e.g. welding machine, hack saw, file etc.

Performance Evaluation

After development of the machine (see Plate 1), the performance evaluation of the motorized juice extractor was carried out to determine the juice extracting parameters for the machine. The extracting parameters considered are:

I. Operating factors: speed at four levels (100, 200, 300, and 400rpm)

ii. Performance parameters: Juice yield, J_y (%), Juice extraction efficiency, E_E (%), and Extraction losses, E_L (%)

Test procedure

Some quantities of fresh pineapple, orange and water melon were purchased from a local store in Abia State. The fruits were washed, cleaned and damaged ones discarded. The undamaged ones were weighed into three portions 0.7kg each for juice extraction. The machine was set into operation by the power source and known weights of each fruits were fed in through the hopper and with the aid of gravity delivered into the extraction unit. In the extraction unit, the auger (screw conveyor) crushed, squeezed and pressed the lumps, thus extracting the juice from the fruits. After extraction, the mass of fruits fed into the machine, mass of juice extracted, and mass of residual waste (chaff) were disposed. Different speeds ranging from 100rpm to 400rpm were used in the test of the machine with the help of a variable speed motor and a tachometer for speed measurement. The performance evaluation of the motorized juice extractor was carried out using the following expressions given by Aviara *et al*. (2013) given in equations (15) and (16) thus;

$$J_Y = \frac{100W_{JE}}{W_{JE} + W_{RW}}\% \;\ldots\ldots\ldots\; (15)$$

$$E_E = \frac{100W_{JE}}{xW_{FS}}\% \;\ldots\ldots\ldots\ldots\; (16)$$

$$E_L = \frac{W_{FS} - W_{JE} + W_{RW}}{W_{FS}}\% \;\ldots\ldots\; (17)$$

Where: W_{JE} is the Juice extracted (kg), W_{RW} is the Residual waste (kg), W_{FS} is the Feed sample (kg), J_Y is the Juice yield (%), E_E is the Extraction efficiency (%), E_L is the Extraction loss (%) and x is the Juice constant. The juice constants used in this study were adopted from Aviara *et al*. (2013). They are 0.8, 0.78 and 0.91 for peeled pineapple, orange and water melon respectively. The results obtained from the design and the testing of the machine was presented in a Table 4 and Figures 3-4 respectively. The extraction losses and machine efficiencies were also calculated for pineapple, orange and water melon respectively.

Results and Discussion

The result of the fabrication process for the juice extractor components is shown in Table 1.

Table 1: Results of the fabrication process for the juice extractor

Component	Material used	Procedure	Tools used
Motor casing	Mild Steel	The work piece was cut into 15 pieces of required dimensions and welded to form the motor casing	Hammer, arc welding, drilling machine, grinding machine
Auger	Stainless Steel	The work piece was made into a helix and welded to the hollow shaft	Arc welding machine, grinding machine, hammer, drilling machine
Cylindrical barrel	Stainless Steel	The work piece was made into a cylindrical shape of required dimension and cone shaped end was welded to it.	Arc welding machine, grinding machine, hammer, drilling machine
Juice outlet	Stainless Steel	The work piece was made into a cylindrical shape and then sliced at an angle to give it a better look.	Grinding machine, Arc welding machine, filing machine.

Cost Analysis of the Juice Extractor

An important factor in design and construction is the cost of production. The purpose of fabrication would not be achieved if at the end of production, the produced machine is not affordable by the targeted customers. This factor has been duly considered resulting to the choice of relatively cheap and reliable materials as summarized in Tables 2 and 3.

Table 2: Bill of Engineering Measurement and Evaluation of Production

S/N	Material	Specification	Quantity	Unit Cost (₦)	Total cost (₦)
1	Stainless Steel rod	ϕ 42mm	1	7,000	7,000
2	Stainless steel rod	ϕ 25mm	1	1,400	1,400
3	Stainless steel rod	ϕ 70mm	1	10,600	10,600
4	Mild steel plate	0.5x0.5m	1	3,750	3,750
5	Bolts	M12	25	10	250
6	Motor	1hp	1	20,000	20,000
	Total material cost				**43,000**

Table 3: Labour and Overhead cost

S/N	Type of Labour	Amount (₦)
1	Cost of fabrication and assembly	15,000
2	Cost of transportation and miscellaneous	6,000
	Total Labour cost	**21,000**

Grand Total Cost of the juice extractor = ₦43,000 + ₦21,000 = ₦64,000

Design results of the Juice extractor

The design of the Juice extractor was carried out and the various parameters obtained were shown in Table 4.

Table 4 Design Results for the Juice Extractor

Initial Data	Calculation	Results
$\pi = 3.142$ $r_1 = 0.16\text{m}$ $r_2 = 0.12\text{m}$ $h = 0.3\text{m}$	**Volume of hopper** From equation 1 $V = \frac{1}{3}\pi({r_1}^2 + r_1 r_2 + {r_2}^2)h$	$V = 0.0186\text{m}^3$
$\pi = 3.142$ $\tau = 55\text{MPa}$ $k_b = 1.5$ $k_t = 1.0$ $M = 0.44\text{KNm}$ $T = 5.41\text{Nm}$	**Diameter of screw conveyor** From equation 2 $d^3 = \frac{16}{\pi\tau}\sqrt{(k_b M)^2 + (k_t T^2)}$	d = 40mm
$g = 9.81\text{m/s}^2$ $\delta = 2.45\text{x}10^{-6}\text{m}$ $\pi = 3.142$	**Critical Speed of Shaft** From equation 3 $N_c = \frac{\sqrt{\frac{g}{\delta}}}{2\pi}$	$N_c = 318.5\text{rpm}$
$T = 5.41\text{Nm}$ $D_m = 0.005$ $\mu = 0.58$ $\theta = 3^\circ, \alpha = 14.98^\circ$	**Load that can be lifted by the auger** From equation 5 $W_e = T\,\frac{\frac{D_m}{2}\tan\theta + \frac{\mu}{\cos\alpha}}{(1 - \mu\tan\theta\cos\alpha)}$	$W_e = 33.5\text{N}$
$D_m = 0.005$ $\pi = 3.142$ $n = 7$ $h = 0.004$	**Pressing Area** From equation 7 $A_p = \pi D_m nh$	$A_p = 439.8\text{mm}^2$
$W_e = 3.35\text{KN}$ $A_p = 565.5\text{mm}^2$	**Pressure developed by the auger** From equation 8 $P_r = \frac{W_e}{A_p}$	$P_r = 0.01\text{Mpa}$
$t = 1.2\text{mm}$ $\delta_a = 58\text{Mpa}$ $D_i = 69.5\text{mm}$	**Pressure of the barrel** From equation 9 $P_b = \frac{2t\delta_a}{D_i}$	0.2MPa

$D_s = 40mm$	**First Pitch of decreasing Auger** From equation 10 $P_s = 1.4D_s$	$P_s = 56mm$
$P(X_n) = 0.056m$ $\Pi = 3.142$ $D_s = 0.040m$ $d_s = 0m$ $L = 0.50m$ $N = 300rpm$	**Inlet velocity of the raw material** From Equation 10 $v = \frac{P(X_n)\frac{\pi}{4}(D_s{}^2 - d_s{}^2)N}{4D_sL}$	$v = 0.264m/s$
$L_2 = 0.50 - 0.056 = 0.44$ Similarly, $L_3 = 0.44 – 0.05 = 0.39$ $L_4 = 0.39 – 0.044 = 0.35$ $L_5 = 0.35 – 0.040 = 0.31$ $L_6 = 0.31 – 0.035 = 0.28$ $L_7 = 0.28 – 0.031 = 0.25$	**Pitch of the decreasing pitch auger** From Equation 11 $P(X_n) = \frac{4vD_sL}{\frac{\pi}{4}(D_s{}^2 - d_s{}^2)N}$	$P(X_2) = 0.05m$ $P(X_3) = 0.044m$ $P(X_4) = 0.040m$ $P\quad(X_5) = 0.035m$ $P(X_6) = 0.031m$ $P(X_7) = 0.028m$
$D_s = 40mm$ $d_s = 20mm$ $P_s = 56mm$ $\Phi = 0.9$ $\pi = 3.142$	**Theoretical capacity of the extractor** From Equation 12 $Q_e = 60\times\frac{\pi}{4}(D_s^2 – d_s^2) P_s N_s \varphi$	$Q_e = 21$ kg/hr
$Q_e = 21kg/hr$ $\rho = 734 kg/m^3$ (orange) $\rho = 700 kg/m^3$ (pineapple) $\rho = 678 kg/m^3$ (water melon)	**Volumetric capacity of the machine** From Equation 13 $Q_{vc} = \frac{Q_e}{\rho}$	$Q_{vc} = 0.028\ {}^3/hr$ $Q_{vc} = 0.030\ {}^3/hr$ $Q_{vc} = 0.031\ {}^3/hr$
$Q_{vc} = 0.02m^3/hr$ $l_s = 0.5m$ $\rho = 678kg/m^3$ $g = 9.81 m/s^2$ $F = 1.5$	**Power required for extraction** From Equation 14 $P_e = 4.5\times Q_e\times l_s\times g\times F$	$P_e = 0.70KW$
$P_t = 0.065KW$ $\eta = 75\%$	**Power of motor** From Equation 15 $P_m = \frac{P_t}{\eta}$	$P_m = 1hp$

The maximum speed of the motor used is 300rpm and this did not exceed the critical speed of the shaft from equation 3. At this critical speed, the shaft tends to whirl and as such cause vibrations which in turn increased the total power consumption of the machine. From equation 5 and 8, it shows that the pressure the barrel can withstand (0.2MPa) is greater than the pressure developed by the auger shaft. Therefore the barrel can withstand the extraction pressure without bursting.

Machine performance results

The Performance results for Extraction Efficiency, Juice Yield, Extraction Losses and Extraction Time for Orange, Pineapple and Water Melon follow the same graph pattern, and as such the discussion of the result for these parameters is the same. It is also worthy of note that with speed above 300rpm, the efficiency and extraction loss changed, which conforms to the whirling of the shaft at such speed.

Extraction Efficiency (E_E)

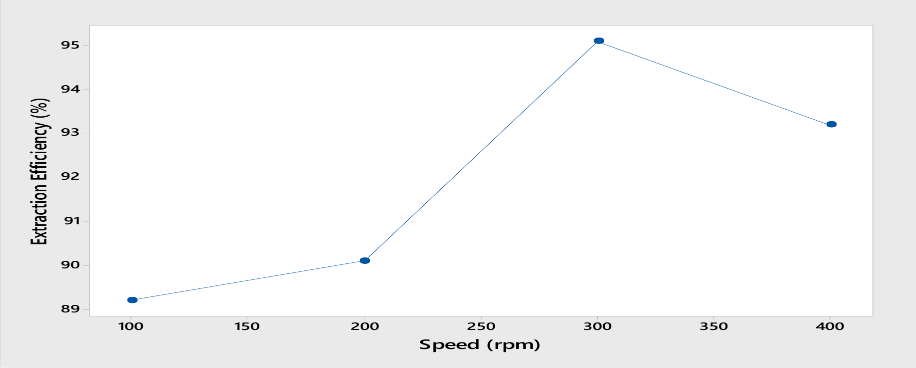

Figure 3: Variation of juice extraction efficiency versus Extraction Speed for orange

The efficiency pattern shown in Figure 3 shows that as the speed of the machine shaft increased, the efficiency increased to a speed of 300rpm. As the speeds were changed, the efficiencies produced varied. This shows that, a change in speed directly affects the efficiency of the machine. It was discovered from the tests that the machine, when operating at 300rpm has the efficiency of 92.1%, 96.8% and 98.1% for Orange, Pineapple and Water Melon respectively. The machine efficiency increased as the speed increased, up to a speed of 300rpm where the efficiency started declining. The lowest efficiency was recorded at a speed of 100rpm.This is due to the slow speed at which the shaft was turning. This made the fruits take a longer time to travel through the extraction chamber of the machine. Also, the centrifugal force developed in the machine that drives the fruits to the outer edges of the auger and against the cone-shaped barrel surface for high juice extraction was inadequate. This force, known as the centrifugal force, depends on the mass of the object, the speed of rotation, and the distance from the center. The greater the speed of the object, the greater the force (UVPS, 2013). The magnitude of this force increased as the speed increased to 300rpm where the force was enough to aid juice extraction. At a speed of 400rpm, the centrifugal force produced is too high. Therefore, the fruits do not have adequate time to move within the internal surface of the cone-shaped barrel for extraction. Also, due to the high speed, the fruits travel through the extraction chamber at a faster rate. When this happens, the traces of the original input are found coming out of the outlet. All these caused a decrease in the efficiency of the machine at speeds higher than 300rpm. The efficiency of the machine depends on the type of fruit used. Fruits with more juicy content tend to have more efficiency than fruits with low juice content or high fibre content. Thus, performance tests show that the extraction efficiency of the motorized juice extractor depends on the nature of fruit from which juice is to be extracted, and the extraction speed of the machine. Similar observation was posited by Gbabo *et al*. (2013) and Aviara *et al*. (2013) for other juice extractors.

Juice Yield (J_y)

More juice was yielded from Water Melon fruits followed closely by Pineapple fruits than orange. This might be because pineapple and water melon fruits are more succulent in nature compared to orange. As a result, more juice was extracted at each operating speed from pineapple and water melon fruits with the juice extractor than with the orange. In general, the juice yield of the machine for all the fruits tested, decreased as the machine operating speed increased (Figures 4).

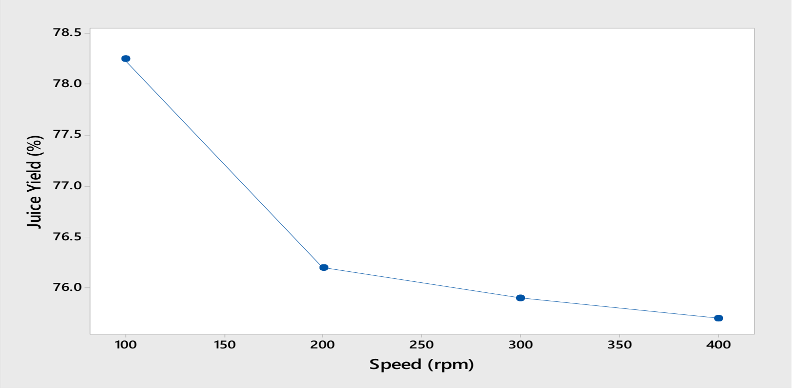

Figure 4: Variation of Juice Yield versus Extraction Speed for orange

Similar observations were made by Adebayo *et al*. (2014), Badmus and Adeyemi (2004) and Olaniyan (2010) for other juice extractors. At high speeds, there is reduction in juice extracted even from pineapple and water melon despite the succulent nature of the fruits. This may be because of losses arising from the vibrations of the machine at high operating speeds, causing splashing of juice to the walls of the machine, thus reducing the yield. This is in agreement with the observations of Adebayo *et al.* (2014). Hence, a controlled speed should be maintained when operating the machine for juice extraction from fruits in order to obtain high yield of the juice.

Extraction Time

The graph pattern in Figure 5 for the fruit samples indicates an inverse proportionality between extraction time and speed. Hence, increase in speed yields a corresponding decrease in the extraction time.

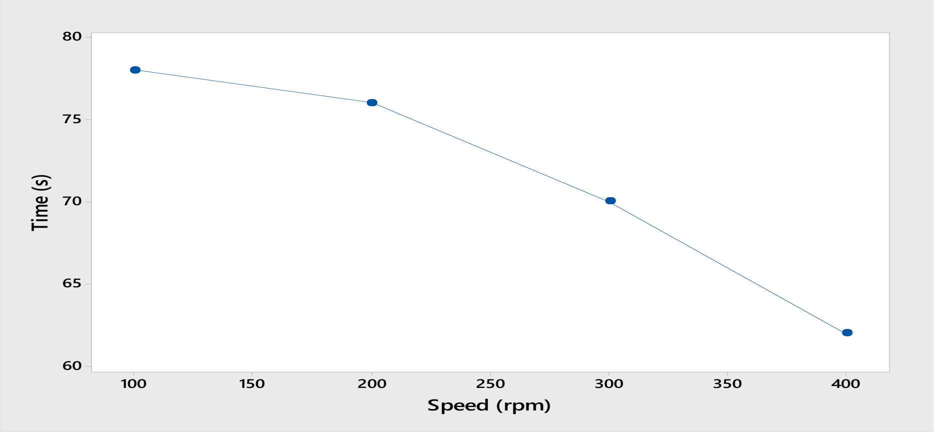

Figure 5: Variation of juice extraction Time versus Speed for orange

This could be due to the rate by which the conveyor carries the fruit along its decreasing pitch. Nevertheless, a further increase in speed revealed less extraction time but with low Juice Yield, which would defeat the purpose of the development of this machine.

Capacity of the machine

A mass of 700g of orange, pineapple and water melon each were used during each test at the various speeds. On average, the machine has a capacity of 13kg/hr. The capacity of this machine has an effect on the amount of work that can be done in a day and how domestically the machine can be used. As the machine capacity increases, the number of hours required to complete an operation naturally declines (William, 2013).

Conclusion

The design, development and the testing of the Juice extractor were successfully studies. All the materials needed in the construction were obtained locally. The machine was portable and easy to operate, assemble and maintain. The average juice extraction efficiency at 300rpm for pineapple, orange and water melon fruits were 96.80%, 95.10% and 98.10% respectively. The juice yield at 300rpm for pineapple, orange and water melon were 81.60%, 75.90% and 91.60% respectively. Juice extraction losses for pineapple, orange and water melon were 5.10%, 2.40% and 2.52% at 300rpm respectively. The innovative Juice extractor cost was ₦64,000, implying affordability for small-scale enterprises, hospitals, hotels, companies and households. In order to further improve on the efficiencies of the machine, the perforations on the inner cylinder of the barrel should be increased to allow free flow of the extracted juice. Also, a sieve should be incorporated close to the juice outlet to ensure pure juice extract. Nevertheless, the sieve should also be easy to remove when it clogs. Finally, the study established that the efficiency of extraction of a juice extractor depends on the speed of extraction*, (rpm)*, and properties of the extracted fruits.

References

Adewumi, B.A. and Ukwenya, A. G. (2012). Design, Fabrication and Preliminary Evaluation of a Mango Juice Extractor. Manuscript prepared for publication in the *Journal of Post-harvest Technology, Germany.*

ASAE (1993). Auger flighting design considerations. ASAE Standards, 40th Ed. EP389.1. St. Joseph, Michigan. Pp. 33-37.

Aviara, N.A., Lawal, A.A., Nyam, D.N. and Bamisaye, J. (2013). Development and performance evaluation of a multi-fruit juice extractor. *Global Journal of Engineering, Design and Technology.* 2(2):16-21.

Badmus, G.A. and Adeyemi, N.A. (2004). Design and fabrication of a small scale whole pineapple fruit juice extractor. Proc 5th Int. Conf. and 26th Annual General Meeting of the Nigerian Institution of Agricultural Engineers, 26:285–291.

Bhandari, V.B. (2004). Design of Machine elements. Tata McGraw Hill publispage numbers?hing Company Limited. New Delhi. Pp. 45-56.

Eyeowa, A. D., Adesina, B. S., Diabana, P. D. and Tanimola O. A. (2017). Design, Fabrication and Testing of a Mango juice Extractor for Small Scale Applications. *Current Journal of Applied Science and Technology,* 22(5): 1-7.

Gbabo, A., Liberty, T.T. and Akingbala, A.S. (2013). Design, Construction and Performance Evaluation of a bush mango juice and seed extractor. *International Journal of Engineering Research and Technology,* 2(11): 2601-2608

Hall, A. S., Holowenko, A. E. and Laughlin, H.G. (2002). Schaum's outline series theory and Problems of machine design. (1st Ed.). *New York: McGraw-Hill Companies, Inc.,* (Chapter 12). Pp. 44-54.

Khurmi, R. S. and Gupta, J. K. (2008). A textbook of Machine Design. (14th ed.). New Delhi: Eurasia Publishing House (PVT) Ltd., (Chapters 7 & 14).

Muhammad, R.H., Hionu, G. C. and Olayemi, F. F. (2012). Assessment of the post-harvest knowledge of fruits and vegetable farmers in Garun Mallam L.G.A of Kano, Nigeria. *International Journal of Development and Sustainability,* 1(2):510-515. ISSN: 2168-8662.

Olabisi, O.I. and Adelegan, G. O. (2015). Design, Construction and Performance Evaluation of Citrus Fruits Juice Extractor. *International Journal of Engineering and Technology*. 4 (5): 1372-1378.

Olaniyan, A.M. (2010). Development of a small scale orange juice extractor. *Journal for Food Science Technology,* 47(1): 105-108

Onwualu, A. P., Akubo, C. O. and Ahaneku, I.E. (2006). Fundamentals of engineering in Agriculture (1st Ed.). Immaculate Publications Ltd. Lagos, Nigeria. Pp. 259-262.

Ryder, G.H. (1985). Strength of materials (3rd Ed.) London: Macmillan Publishers Ltd. (Chapter 15).

Shreeneet, R. (2014). Selection of Machining Parameters on Radial Drilling Machine Tool: An Expert System Approach.

UVPS (2013). University of Virginia Physics show. Centripetal and Centrifugal Force, Available at:http://phun.physics.virginia.edu/topics/centrifugal.html, [Accessed 29/05/14]

William, E. (2013). Ag Decision Maker, Department of Economics University Extension, Iowa State University, *Available at: http://www.extension.iastate.edu*