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Research Article

Development and Performance Evaluation of Hand Operated Screw Juicer for Small Scale Application

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ABSTRACT

Nutrients from fruits are lacking in most African diets despite their importance. This results in malnutrition and diseases. Some of the factors responsible for these dietary deficiencies are income level and technologies to address postharvest losses. A hand-operated screw juicer was developed in this technical brief to address some of the problems. The machine developed uses screw principle for fruits mastication and juice extraction. The screw juicer performance was tested based on extraction capacity, efficiency and number of runs. Bivariate linear regression was the statistical model used to understand the relationship between the explanatory variable, x (number of pass/runs) and the response variable, y (extraction capacity/efficiency). For orange, cucumber, pineapple, golden melon and watermelon, the efficiencies (%) are respectively 79.30, 48.68, 68.96, 56.41 and 56.52 at single pass. Also, the extraction capacities of the machine (L h-1) are respectively 6.38, 5.08, 9.16, 7.84 and 10.48 for the fruits. The efficiencies are higher with orange and pineapple due to fibrous nature of the fruits. Pineapple and watermelon gave higher extraction capacity due to higher water content and juicy nature, at 5 and 7 runs respectively. The model (Y = -49.29X1 + 295.71 ± 89.75) from the analysis using watermelon reveals machine extraction capacity in volume is a function of number of runs. The machine reached its highest extraction capacity of 10.48 liters in 1 hour at 7 runs. This extraction capacity makes the machine fit to meet daily dietary requirements (400 g per person, an equivalence of 380 ml) of more than 4 households if operated for one hour. The machine can be adopted for use by small scale processors as it is affordable, less stressful and easy to maintain.

Keywords: *Crank, Mastication, Juicer, Hand-operated, Extraction-capacity*

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INTRODUCTION

Fruits and vegetables lose a lot of their nutrients quickly since they continue to metabolize and breathe after harvest. At this stage, oxygen in the atmosphere is consumed by the fruits to produce heat, carbon dioxide, ethylene gas and moisture. When the process continues for prolonged time, the produce ripens and the quality degrades. Aerobic respiration of the fruits causes breakdown of organic compounds in the fruits to simpler molecules to cause decay with the release of energy (Delphine *et al*., 2020).

Postharvest losses in fruits and vegetables in Nigeria are estimated to be about 50% annually. This is a worrying situation because fruits and vegetables that are meant to complement other food items for healthy diets are wasting away. Unfortunately, fresh preservation of the fruits requires a lot of investment (NSPRI, 2023).

From empirical facts gathered, it can be inferred that some of the factors responsible for postharvest losses of these highly perishable products are seasonal glut, lack of storage facilities, lack of habit of value addition on harvested products through processing, lack of processing facilities, poor market structure and information on products sales, poor post-harvest handling and management, etc. (Yahaya and Mardiyya, 2019). Postharvest losses from food crops and fruits should be seen as a disservice to humanity, most especially in a country like Nigeria where sizable number of citizens is suffering from lack of access to quality foods. If appropriate technologies are not explored for value addition, the loss may be very unbearable for farmers and stakeholders in the nearest future.

According to World Health Organization (WHO, 2021), it was recommended that at least 400 g of fresh fruit juice should be taken each day by an average individual to boost his or her health for nutritional benefits. Report by WHO (2019) also reveals that 3.9 million of deaths cases recorded worldwide in 2017 were attributed to not eating enough fruit and vegetables. Further, insufficient intake of fruit and vegetables was estimated to cause around 14% of death cases from gastro-intestinal cancer worldwide; 11% of ischemic heart disease, and 9% of stroke cases (Afshin *et al*., 2019).

Health benefits of fresh fruit juice cannot be overemphasized. Antioxidants in fruits can prevent cell damage caused by oxidants and unstable molecules moving in the body (Labo *et al*., 2010). The juice also contains most of the vitamins, minerals and plant chemicals (phytonutrients) found in the fruit. According to Zeratsky (2022), it is believed that drinking fresh fruit juice is better than eating whole fruits because the body can absorb the nutrients better than stressing digestive system to process the fibers in fruits for onward absorption into the body. However, there is a need for scientific evidence on the power fruit juice has in reducing risk of being prone to cancer, boosting immune system, removing toxins from the body, aiding digestion and helping to lose weight.

Over the years, different designs of motorized juicers have been introduced to the market to overcome the challenges of poor post-harvest handling and processing of fruits; but those designs have not gained wide adoption by marginal farmers due to highly prohibitive cost. Those who even use them by economy of scale cannot afford their high cost of maintenance. Eyeowa *et al.* (2017) developed a juice extractor with polytetrafluoroethylene (PTFE) to beat down the cost of production so as to make it affordable for orchard farmers. However, researches have proven that human exposure to Teflon is carcinogenic since chemical used in the manufacturing process (perfluorooctanoic acid, PFOA) has a link with cancer (Pietrangelo, 2020). According to Bochanic (2022), the United State National Health and Nutrition Examination Survey found PFOA in the blood samples of 98% of participants examined. The use of Teflon as a major component of food processing machine should therefore be discouraged.

A juicer is a machine used in extracting juice out of different types of fruits, leaving pulp, seeds and peels behind as byproducts. Juice extraction can be through tapered screw principle, pneumatic pressing, centrifuge separation, rotating blades, triturating discs, masticating teeth, etc. This research endeavour is therefore geared towards designing and fabricating a low cost screw juicer for small scale application to aid the culture of value addition. This will serve to address post-harvest losses of fruits during the time of seasonal glut and as well assist in contributing to dietary requirements of food by nutritionists.

MATERIALS and METHODS

Design Philosophy

The screw juicer uses the change of gap of the tapered screw shaft to build pressure sufficient enough to squeeze the flesh of fruits fed in, to extract the juice. The two operating principles combined by the transmission shaft are material transport within the squeezing chamber and squeezing effect via compression. This type of extraction principle is the most widely used for fruits as the design and operating principle are suitable for small scale application.

Design Consideration

Some relevant factors were considered in the design and development of the hand operated juice extractor; such factors include power requirement, ease of replacement of various components, labour requirement, ease of mobility, possibility of machine duplication, safety of operation of parts, cost of construction, types of load and stresses, machine kinematics and cost of maintenance. The machine will be very easy to maintain as it does not require mechanical power like an oil engine or electric motor to operate. Stainless steel plate of 2 mm thickness was considered for the construction of hopper and the squeezing chamber to avoid shearing of parts or machine failure while in operation. The tapered screw shaft operated by lever arm impacts strong squeezing force in fruits fed in to achieve extraction effect by the juicer assembly. The shaft of the screw juicer was made of stainless steel to avoid food contamination.

Materials Selection

***Table1.** Materials used for machine fabrication.*

Machine Element	Criteria for Material Selection	Materials Selected	Dimension	Remark
Hopper	Must allow free flow of materials into squeezing chamber	Stainless steel of 2 mm thickness	240 mm x 75.5 mm x 2 mm thickness	Machined
Transmission Shaft	Machinability, high tensile/compression strength, low notch sensitivity factor, ductile, torsional rigidity, stiffness, etc.	Stainless steel rod	$\emptyset\ 25mm, 220mm\ l$	Machined
Squeezing Chamber	Ability to withstand vibration and squeezing force	Stainless steel of 2 mm thickness	$diameter, \emptyset\ 82mm$ tapered inward	fabricated
Bearing	Compressive strength, fatigue strength, thermal conductivity, corrosive resistance, etc.	Stainless steel shaft $diameter, \emptyset\ 60\ mm$ Check and write	Outer diameter, $\emptyset b\ 60mm$ Inner diameter, $\emptyset s\ 25mm$, width, $H - 30mm$	Bought readymade
Lever Arm/Crank	Must be firm, free to rotate and must have torsional rigidity	mild steel rod	$Diameter, \emptyset\ 25$ mm, 200 mm long	Machined
Support Frame and Base	Strong ability to withstand compression strength	Galvanized hollow pipe $\emptyset\ 34\ mm$ & stainless steel rectangular platform	Rectangular platform dimension: L x B x T, where L is length, B, breadth and T width	Constructed
Pulp Outlet	Must allow free flow of material	Stainless steel plate folded into cone like hollow pipe (2 mm thick)	249 mm 37 mm x 3 mm	Constructed
Juice Outlet	High shear strength and ability to sustain large permanent deformation to the point of fracture.	Stainless steel screen of 3 mm pore space	15 mm x 10 mm	Bought
Bearing Housing	Must be strong enough to withstand bearing pressure and protect the bearing from outside particles	Mild steel plate 3 mm thick	$\emptyset\ 60mm$ x 70 mm long	Constructed
Screen	Must have ability for both laboratory scale and industrial scale size separation (strong sieving ability)	Stainless steel of 3,000 micron (pore space)	3 mm screen in the dimension of squeezing chamber	Bought readymade and cut to size

Design Calculations

Input power requirement

The input power can be determined from the name plate information of a prime mover used to power a machine. It can also be determined from the drive for the transmission shaft of the machine. In the design, the input power for the hand operated screw juicer was found from the Mathematical model by Belonio (2004) on human power estimation for farm work. It is as stated in Equation 1.

$Pg\ (Hp) = 0.35 - 0.092 Logt(min)$ Belonio (2004) (1)

Human power is given as $Pg\ (Hp) = 0.35 - 0.092\ Logt(min)$
To find $\boldsymbol{P_g}$ when t = 1 h = 60 minute.
P_g = 0.35 – 0.092log 60 = 0.35 – 0.092 x 1.7782
P_g(Hp) = 0.35 – 0.1636 = 0.1864 Hp

1Hp = 0.746 kW
0.1864 HP = x
$x = 0.746\ x\ 0.1864$
$P_g = 0.139\ kW$
$P_g = 139\ W$

Hence, human power requirement by one human operator on the screw juicer for one hour is **139 W.**

Load requirement

In estimating load requirement, the squeezing force of the screw shaft is calculated using power requirement of the entire machine assembly.

$$Power, P = F\ x\ \omega r = F\ x\ v = \frac{F\ x\ \pi DN}{60} \quad (2)$$

Where F is squeezing force on the flesh of the fruit, ω is angular velocity of the lever arm
r is the radius of the lever arm, v is the linear velocity of the transmission shaft and P is the power transferred from the cranking arm to squeezing chamber.

$$F = \frac{P}{v} = \frac{P}{\frac{\pi DN}{60}}\ (N) \quad (3)$$

Where p is the power from the cranking arm and v is the velocity of transmission. It is assumed that Power, P transferred from the cranking arm to squeezing chamber is constant.

Given the following parameters: ω is 75 rpm, D is 20 mm = 0.02 m, squeezing force, F_{sq} can be found.

$$At\ 75\ rpm,\ F = \frac{P}{v} = \frac{P}{\frac{\pi DN}{60}} = \frac{139}{\pi\ x\ 0.02\ x \frac{75}{60}} = 1.769\ kN$$

Torque requirement

The torque requirement is found using the formula given below.

Torque, T transmitted through shaft = queezing force F x radious, R of screw shaft

$$Torque, T = F\ x\ R \quad (4)$$

For squeezing force, F is 1,769 and R is 0.02 m, then:

Torque, $T = 1{,}769\ x\ 0.02 = 35.38$ Nm

Design capacity of the screw juicer

A screw juicer compresses fresh fruits between the layers of screw and the squiring chamber to separate pulp from juice. The design capacity of the screw juicer is as estimated in Equation 5 below:

$$Q = 60\ x\ \left(\frac{\pi}{4}\right) x\ D^2 x\ S\ x\ N\ x\ \alpha\ x\ \rho\ x\ C$$ (Eyeowa *et al.*, 2017) (5)

Q = screw capacity (kg h^{-1}.)

D = screw diameter (m) = 20 mm = 0.02 m

S = screw pitch (m) = 0.01 m (see Equation 7 for details)

N = screw speed (rpm) = 72.5 rpm (estimated from crank arm rotation)

α = loading ratio = 0.3 (materials is averagely a flow-able material)

ρt = material loose density $\left(\frac{kg}{m^3}\right)$ = 1030 kg m^{-3} (orange fruit)

C = inclination correction factor = 1.0 (since the screw has zero inclination)

$Q = 60\ x\ \left(\frac{\pi}{4}\right) x\ 0.02^2 x\ 0.01\ x\ 72.5\ x\ 0.3\ x\ 1030\ x\ 1$

$Q = 4.22\,\frac{kg}{h}$

$$V = \frac{Q}{\rho} \quad (6)$$

where V is the volumetric capacity (m^3 h^{-1}.) and ρb is the bulk density of fruit

if ρb (orange juice) = 440 kg m^{-3}

$V = \frac{Q}{\rho} = \frac{4.22}{440} = 0.0096\,\frac{m^3}{h}$

$V = 9.6\,\frac{L}{h}$. Therefore, the extraction capacity for fruit processed is 9.6 liters per hour. The value is subject to type fruit processed since loose density varies for the type of fruit processed.

Screw pitch design

$$S = \frac{4VDL}{\frac{\pi}{4} x (D^2 - d^2) N}$$ (Eyeowa *et al.*, 2017) (7)

Screw pitch, S = ?, the inlet velocity of raw material, V is 0.025 m/s (Assumed). Outside diameter of screw, D is 30 mm, the inside diameter of screw, d is 20 mm. The length of the screw shaft, L is 100 mm, the shaft speed, N is 75 rpm.

$S = \frac{4VDL}{\frac{\pi}{4} x (D^2 - d^2) N}$

$S = \frac{4\ x\ 0.025\ x\ 0.03\ x\ 0.1}{\frac{\pi}{4}\ x\ (0.03^2 - 0.02^2) x 75}$

$S = 0.0102$ m = 10.2 mm

Shaft diameter design

$d = \left(\frac{16}{\pi \tau max} \; x \; T\right)^{\frac{1}{3}}$ (Khurmi and Gupta, 2005; Adetola *et al.*, 2014) (8)

From Equation 4, Torque, T is 35.38 N m. If maximum allowable stress of the screw shaft,

τ max *is* 6.67MPa, then diameter of screw shaft can be calculated using Equation 8

$d = \left(\frac{16}{\pi \; x \; 6.67 x 10^{6}} \; x \; 35.38\right)^{\frac{1}{3}}$

$d = 0.030005 \text{ m} \; \approx 30 \text{ mm}$

For torsional rigidity, the deflection angle of transmission shaft is given as $\theta = \frac{\tau L}{GR}$ (Khurmi and Gupta, 2005). (9)

G = Modulus of rigidity for stainless steel = $120 \; x \; 10^{9}$ Pa

R, radius of screw shaft is 15 mm

L, length of shaft is 100 mm

$\theta = \frac{\tau L}{GR} = \frac{6.67 \; x \; 10^{6} \; x \; 0.1}{120 \; x \; 10^{9} \; x \; 0.015} = \; 0.000371$ - Since the value is less than 0.003, it is within acceptable region.

Machine Description and Operation

The hand operated screw juicer has four main components: a cranking unit, squeezing unit, pulp outlet, juice outlet and member frame. The squeezing unit has a screw shaft inside a barrel made of stainless steel to avoid food contamination. The squeezing chamber accommodates diced fruit flesh of varying geometries fed into it through the hopper to masticate the fruit and at the same time squeeze out the juice. The screw shaft is powered by the rotation of the cranking arm operated manually at the peripheral of the machine assembly. The masticating and compression force generated in the process assists in squeezing the juice out of the flesh. The juice is afterwards collected through juice outlet while pulp is allowed to be discharged through pulp outlet.

As soon as a batch is completed after many runs depending on the type of fruit processed, another batch of diced fruits is fed in to continue the operation until all the juice contained in the batch is fully squeezed out. The cranking unit is the section of the machine assembly that provides rotational power to the screw shaft masticating and squeezing the fruit flesh. Human power is used to propel the lever arm of the cranking unit. The crank unit is made of 25 mm mild steel rod and two bearings housed by stainless steel plate of 4 mm thickness. The juice outlet provides the passage for flow of juice out of the squeezing chamber through the 3 mm screen at the outlet section directly under the chamber. The outlet for pulp is immediately after the screw shaft at the peripheral of the compression chamber (see Figures 1, 2 and 3 for details of the design). It is made of stainless steel and formed into shape of 25 mm diameter to create pressure sufficient enough to squeeze out the juice and release the pulp. The member frame is the support for the entire assembly. The design of the frame is in form of a pew with rectangular base platform. The pipe linked to the base helps to hold the squeezing chamber in place. The legs of the operator are placed on both sides of the base to further strengthen the firmness of the machine while in operation. See Figures 1, 2 and 3 for details on all the units of the machine assembly.

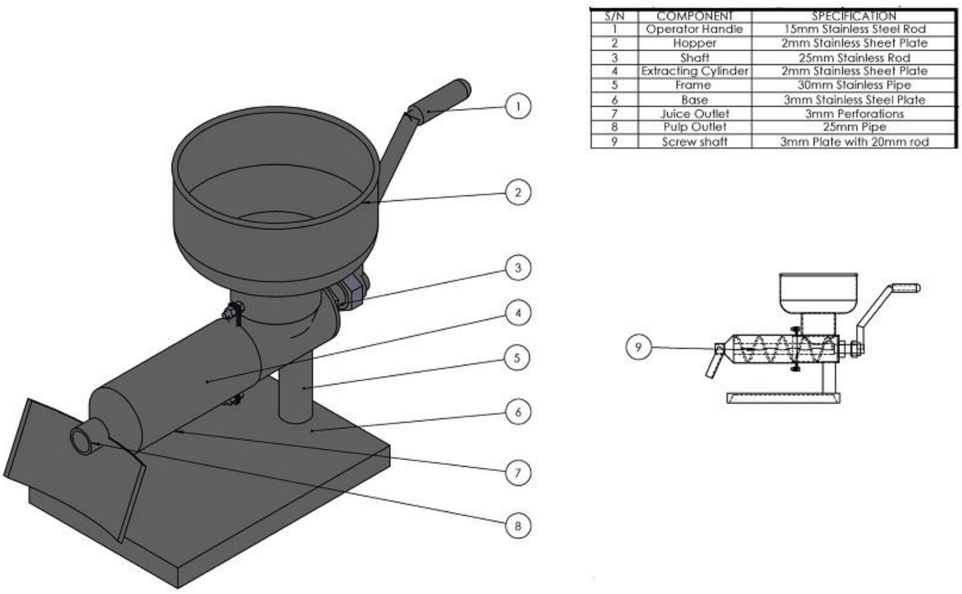
Cost Estimation of the Hand Operated Screw Juicer

Cost of engineering products can broadly be grouped under direct or indirect costs. The costing of the newly designed and fabricated screw juicer was based on the detailed factorial estimate method. This is because fabrication of the machine is complete and detailed breakdown and estimation of component parts is possible. The cost analysis of the machine is as shown in Table 2.

Table 2. *Bill of Engineering Measurement and Evaluation (BEME) for the screw juicer.*

S/N	Materials	Quantity	Unit Price ($)	Total ($)
1	Cranking Arm ($\emptyset 25mm$ rod & 110 mm long)	1/8	17.32	2.16
2	Hopper, Pulp Outlet, Extraction Barrel and Support Base (3 mm stainless steel plate)	1/8	173.32	21.6
3	Screw Shaft (20 mm stainless steel rod) with 10 mm pitch	¼	21.64	5.41
4	Braising Rod for support (30 mm stainless steel pipe)	¼	51.95	12.99
5	Juice Outlet (3 mm thick stainless steel screen)	1/8	86.58	10.82
6	Bearing $\emptyset 25mm$ (internal ∅)	2	3.25	6.50
7	Consumables (electrodes, paint & cutting disc, body filler, etc.)			5.41
8	Transportation			2.16
	Sub-total = $ 67.10			

Materials Cost = $ 67.10
Direct Labour Cost: (Machining of Main Shaft, Bending, welding, painting) = $ 7.58
Indirect/Overhead Cost: = 20% of $ 67.10 = $13.42
Grand-total = Material cost + Labour cost + Overhead cost = $ 67.10 + $ 7.58 + $ 13.42 = $ 88.10



S/N	COMPONENT	SPECIFICATION
1	Operator Handle	15mm Stainless Steel Rod
2	Hopper	2mm Stainless Sheet Plate
3	Shaft	25mm Stainless Rod
4	Extracting Cylinder	2mm Stainless Sheet Plate
5	Frame	30mm Stainless Pipe
6	Base	3mm Stainless Steel Plate
7	Juice Outlet	3mm Perforations
8	Pulp Outlet	25mm Pipe
9	Screw shaft	3mm Plate with 20mm rod

Figure 1. *Pictorial view of screw juicer.*

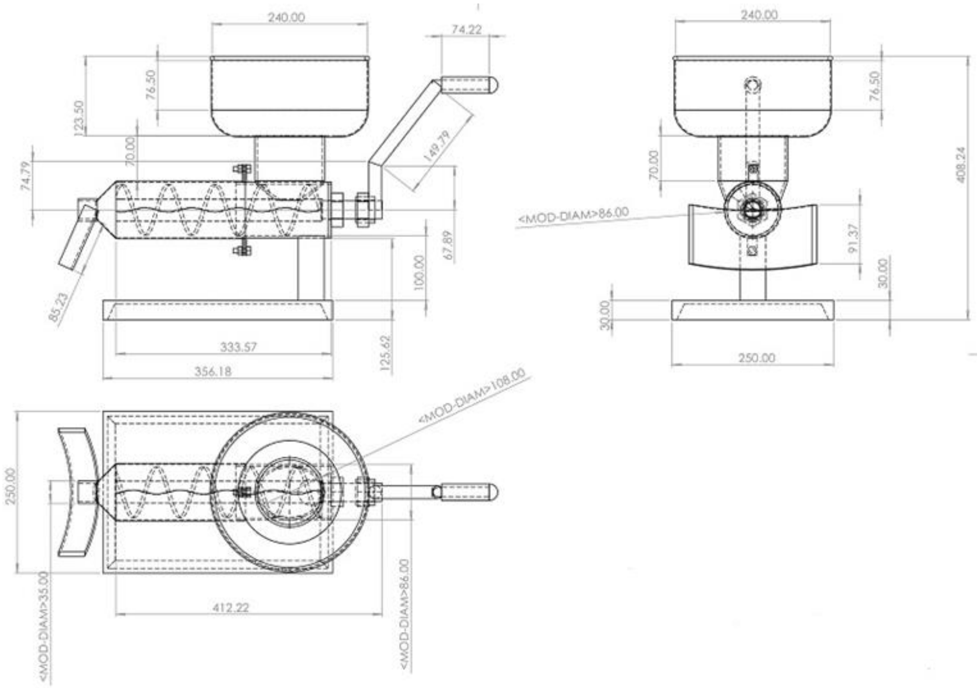


Figure 2. *Autographic projection of the screw juicer (All dimensions are in mm).*

Statistical Analysis

Null hypothesis for variables considered is Ho: $0.5 \leq r \leq 1$; while alternative hypothesis is H_1: $r < 0.5$. Bivariate Linear regression was the statistical model used to understand the relationship between the predictor and the response variable. Y is response variable, βo is intercept on y axis, X_1 / Xn is the predictor and β_1 / β_n is the regression coefficient and ε is the model error (see Equation 10 and 11 for the regression model). Other statistical instrument used is the diagrammatic representation of the evaluation data in quantities (descriptive statistics).

$$Y = \beta_0 + \beta_1 X_1 \quad \text{(Zach, 2020)} \tag{10}$$

$$Y = \beta_0 + \beta_1 X_1 + ...+ \beta_n X_n + \varepsilon \quad \text{(Zach, 2020)} \tag{11}$$

Materials for Evaluation

The fruits used for evaluation of the screw juicer are orange, pineapple, cucumber, golden-melon and watermelon fruits. The instruments for materials evaluation are sensitive measuring scales, stopwatch, recording materials, vernier caliper and measuring cylinder. Variables considered during material's evaluation are material throughput, extraction capacity, speed of rotation of the cranking arm, extraction efficiency, etc.

$$Materials\ throughput\ = \frac{W\ x\ 3600}{t}\ (\frac{kg}{h}) \quad \text{Eyeowa } et\ al. \text{ (2017)} \tag{12}$$

Where W is weight of material processed(kg) and t is extraction time (s)

$$Extraction\ Efficiency\ (\%) = \frac{Vs}{Vt}\ x\ 100 \quad \text{Eyeowa } et\ al. \text{ (2017)} \tag{13}$$

Vs is volume of juice extracted at single pass and Vt is $total\ volume\ \ of\ juice\ in\ the\ fruit$

$$Juice\ Extraction\ Capacity\ = \frac{V\ x\ 3600}{t}\ (\frac{Ll}{h})$$ Eyeowa *et al.* (2017) (14)

Where V is the total volume of juice extracted and t is extraction time in seconds

$$Density\ of\ Juice\ = \frac{m}{v}\ (\frac{kg}{m^3})$$ Eyeowa *et al.* (2017) (15)

RESULTS AND DISCUSSION

The screw juicer developed was evaluated with various types of fruits which include orange, cucumber, watermelon, pineapple and golden-melon. Parameters evaluated are materials throughput, extraction capacity and extraction efficiency. The results are shown in Tables 3 and 4.

Maize sheller developed was evaluated using unshelled maize at various moisture content and speed of rotation of the crank arm to determine the efficiency, shelling capacity and kernel damage. The results of the analysis are as shown in Figures 5 and 6 and Tables 3, 4, and 5.

Tables 3, 4 and 5 show the results of evaluation of the developed maize sheller at various moisture content (MC) ranging from 14 % to 23.2%. The results show kernel breakage reduces as the moisture content of various maize samples used for machine evaluation reduces. Also, highest material throughput (60 kg h^{-1}.) was obtained at lowest MC (14%) and highest angular spend of rotation. The efficiency of shelling was seen to be highest at lowest MC and time (6 - 10 seconds).

Table 3 shows reduction in efficiency of shelling from 100 to 94 percent as the speed of rotation increases from 40 rpm and 120 rpm. It can be inferred that the operation of the machine should be kept at barest minimum level to be able to experience optimum shelling efficiency. Also, kernel damage can reduce significantly if the hand operated sheller is kept at optimally low speed while in operation.

Table 3. Material evaluation of screw juicer using different types of fruits.

S/N	Type of Fruit	Mass of fruits to be processed (g)	Volume of juice extracted (ml)	Number of Pass/runs	Revolution (Crank arm)	Time taken (s)	Mass of juice extracted (g)	RPM (rev min^{-1})
1.	Orange	581.11	245	1	127	110	330.80	69.27
			55	2	38	35	50.00	65.14
			10	3	36	30	13.65	72.00
2.	Cucumber	561.23	180	1	110	112	255.87	58.93
			85	2	36	39	89.53	55.38
			35	3	38	30	44.07	76.00
			40	4	29	26	28.00	66.92
			20	5	30	28	28.38	64.28
			10	6	28	27	15.25	62.22
3.	Pineapple	390.86	200	1	45	48	208.0	56.25
			40	2	20	20	43.5	60.00
			20	3	20	20	31.7	60.00
			20	4	16	17	15.61	56.47
			10	5	13	14	5.0	55.71
4.	Golden-melon	603.20	220	1	86	79	222.8	65.31
			100	2	36	28	107.7	77.14
			20	3	25	25	30.35	60.00
			40	4	25	24	34.22	62.50
			10	5	28	23	9.83	73.04
5.	Watermelon	910.24	390	1	108	87	476.5	74.48
			130	2	53	45	126.0	70.66
			60	3	38	32	66.93	71.25
			40	4	34	28	44.82	72.85
			40	5	22	19	44.82	69.47
			20	6	17	14	22.41	72.85
			10	7	15	12	11.21	75.00
6.	Orange + Cucumber	549.00	220	1	103	97	197.0	63.71
			40	2	25	26	58.0	57.69
			20	3	30	24	16.0	75.00
			10	4	25	16	8.0	93.75
7.	Pineapple + Watermelon	982.54	540	1	160	172	527.41	55.81
			100	2	40	46	98	52.17
			40	3	36	38	40	56.84
			20	4	30	28	25	64.29
			10	5	23	24	13	60.00

The results in Table 3 show volume of juice extracted at different number of passes ranging from three to seven depending on type of fruit processed. The time taken and the revolution of the cranking arm at each number of runs were recorded. Water melon has the highest number of runs followed by cucumber. When either the cucumber or water melon was combined with fibrous fruits like orange or pineapple, the number reduced to 5 for water melon and 4 for cucumber. The implication from this is that the fibrous property lacking in the fruits was compensated for by other fruits combined with them during evaluation.

Table 4. *Extraction efficiency and extraction capacity of the screw juicer for various types of fruits processed.*

S/N	Type Fruit	Density of juice (kg m^{-3})	Extraction capacity (at all possible runs) (L h^{-1})	Materials throughput (at all possible runs) (Kg h^{-1})	Number of Pass	Average RPM	Extraction efficiency (at Single Pass/Runs) (%)
1	Orange	1272.42	6.38	11.95	3	68.80	79.03
2	Cucumber	1170.54	5.08	7.71	6	63.96	48.65
3	Pineapple	1047.62	9.16	12.34	5	57.69	68.96
4	Golden-melon	1038.21	7.84	19.04	5	67.60	56.41
5	Watermelon	1083.87	10.48	13.83	7	72.37	56.52
6	Orange + Cucumber	962.07	6.41	12.12	4	72.54	75.86
7	Pineapple + Watermelon	990.72	8.30	12.24	5	57.82	76.06

Table 4 gives the average value of extraction capacity, materials throughput, and angular speed of rotation and extraction efficiency for each fruit. Orange has the highest extraction efficiency (79.03%) followed by pineapple (68.96%). Also, the machine has the highest extraction capacity for water melon, followed by pineapple. The high extraction volume can be attributed to juicy nature of the fruits. The speed of rotation of the cranking arm ranges from 57.69 to 72.52 rpm. On the average, the cranking arm of each extraction process completes 60 revolutions and above in one minute.

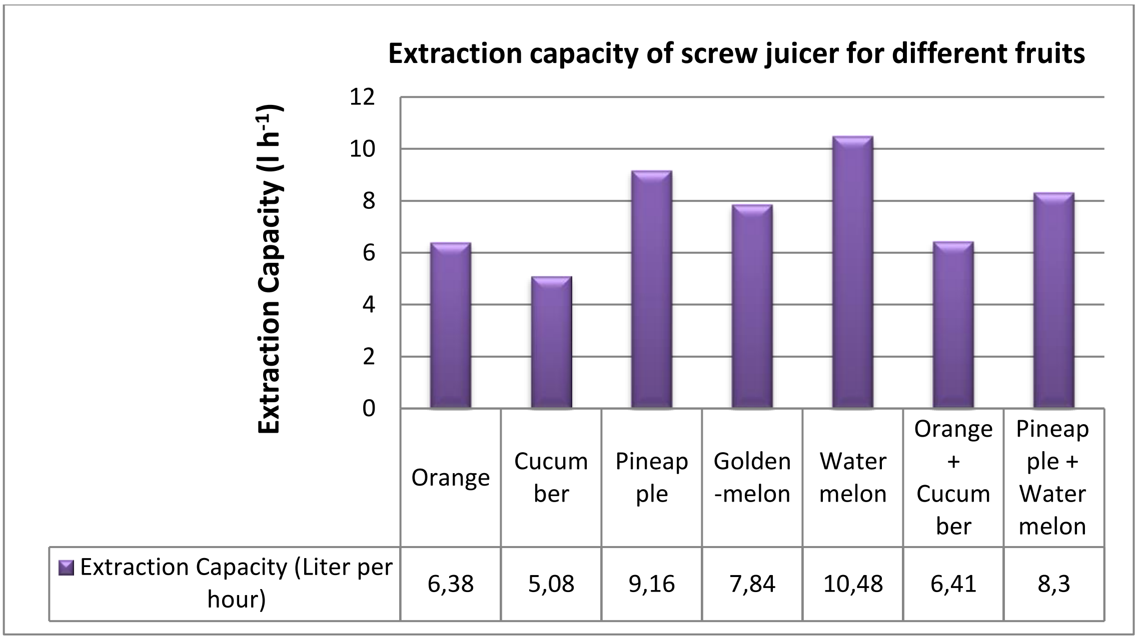
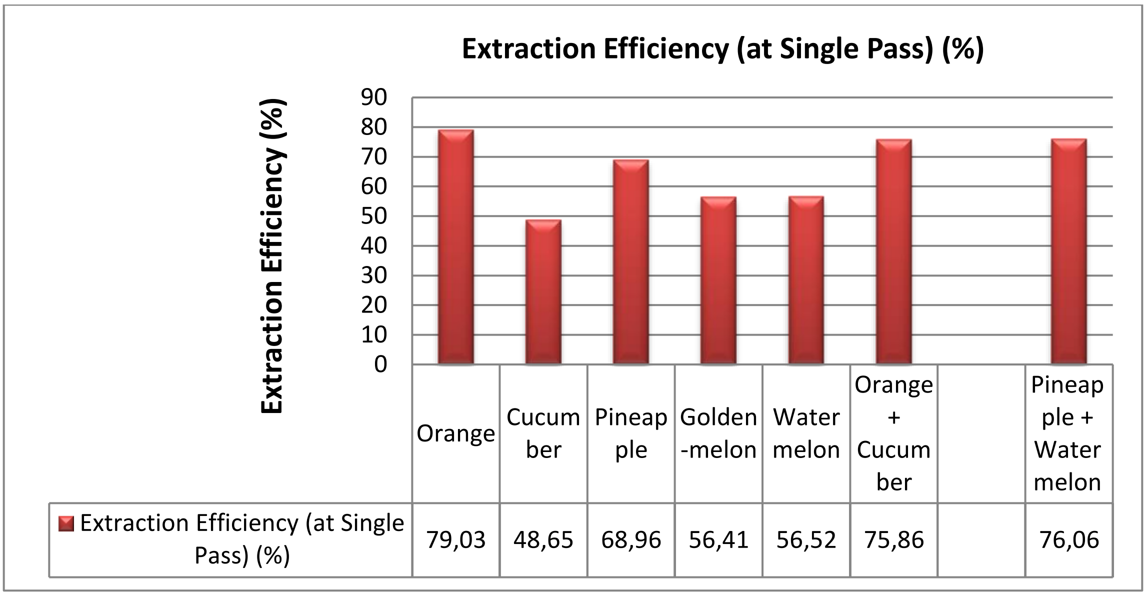


Figure 3. *Chart of extraction capacity of the screw juicer for different fruits.*

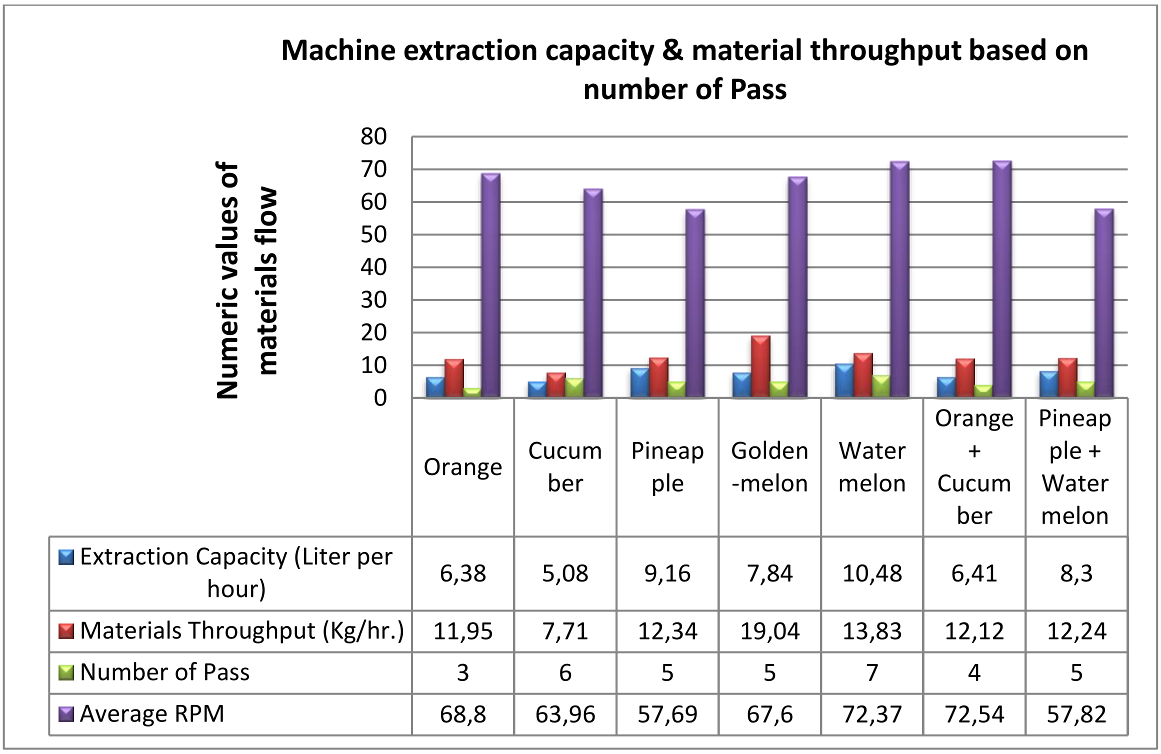
Figure 3 is the chart of extraction capacity of the screw juicer for various fruits processed. The machine extraction capacity was highest with watermelon (10.48 L h^{-1}) and lowest with cucumber (5.08 L h^{-1}). The reasons for the differences in the extraction capacity are due to soluble solid content and water content of the fruits.



	Orange	Cucumber	Pineapple	Golden-melon	Watermelon	Orange + Cucumber		Pineapple + Watermelon
Extraction Efficiency (at Single Pass) (%)	79,03	48,65	68,96	56,41	56,52	75,86		76,06

Figure 4. *Chart of extraction efficiencies of various fruits.*

Figure 4 is the chart of extraction efficiencies of the fruits. The screw juicer efficiency was highest with orange (79.03%) and lowest with cucumber (48.65%). The reasons for the differences in the extraction capacity are due to fibrous nature orange fruit over cucumber and other fruits with low extraction efficiency. Also, pineapple is close to orange in efficiency due to its fibrous property - the property assists in generating enough friction required to masticate and squeeze the juice out of the fruit.



	Orange	Cucumber	Pineapple	Golden-melon	Watermelon	Orange + Cucumber	Pineapple + Watermelon
Extraction Capacity (Liter per hour)	6,38	5,08	9,16	7,84	10,48	6,41	8,3
Materials Throughput (Kg/hr.)	11,95	7,71	12,34	19,04	13,83	12,12	12,24
Number of Pass	3	6	5	5	7	4	5
Average RPM	68,8	63,96	57,69	67,6	72,37	72,54	57,82

Figure 5. *Influence of number of pass on extraction capacity & materials throughput.*

Figure 5 is the charts of materials' throughput of the juicer at varying number of passes. From the chart, golden melon has the highest materials throughput (19.0 kg h^{-1}) followed by watermelon (13.83 kg h^{-1}). It can be inferred that less fibrous fruits give more material throughput as pulp or other waste product.

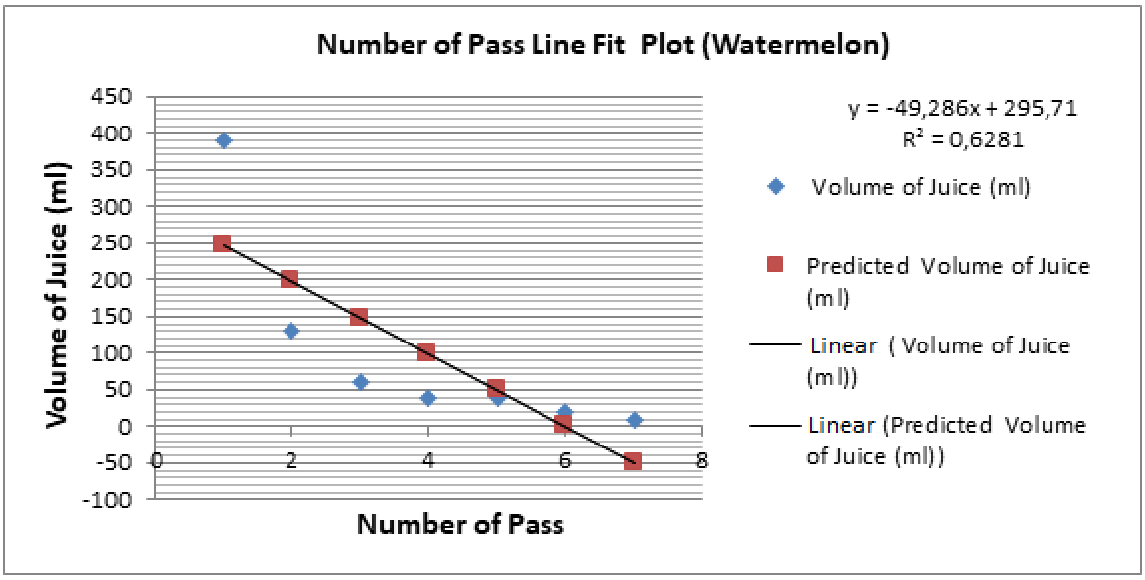


Figure 6*. Relationship between number of pass and volume of juice extracted in one of the evaluation exercises (Watermelon).*

Bivariate linear regression was the statistical model used to understand the relationship between extraction capacity in volume and number of passes for watermelon fruit in Figure 6. The model was developed for watermelon because in the list of the fruits evaluated, it has the highest extraction capacity and highest number of passes. The statistical model of the analysis is given as $y = -49.286x + 295.71 \pm 89.75$. Out of the 910.24 g of water melon fruit processed, 390 ml of juice was extracted at first run – for this value, extraction capacity is 16.14 liters in one hour (see table 3 for details). At second and third run, extra volume of 130 ml and 60 ml were respectively recovered. The volume kept reducing until 10 ml is extracted at seventh run. Total volume of juice extracted from the 910.24 g of fruit is 690 ml in 237 seconds. If the extraction process is kept at single pass or first run, it would have been difficult to recover up to 300 ml of juice. From the foregoing, it can be inferred that what watermelon extraction process cannot meet in efficiency under a single pass is compensated for in multiple passes.

Tables 5 and 6 gave the summary of the output that was used to write the model. β_o is 295.71 ml while β_1 is -49.29 unit and ε is 89.75 ml. Variable X in the model is the number of pass of the extraction process; β_o is intercept on y axis, ε is the model error and variable Y is the extraction volume (in milliliter). For example, every unit increase in number of pass of a particular extraction process, extraction volume increases commensurately (as it adds up). The machine reached its highest extraction capacity of 10.48 liters in one hour at very high pass of 7 units.

Table 5. *Summary Output.*

Regression Statistics	
Multiple R	0.792528
R Square	0.6281
Adjusted R Square	0.55372
Standard Error (ε)	89.74567
Observations	7

The results presented in table 5 shows that 7 observations were used for the model of the predictor (x) and response variable (y). The coefficient of determination, R square being 0.628 implies 62.8% of the variation in the extraction volume can be explained by the number of passes an extraction process (watermelon) experienced. The multiple R value, 0.795 reveals that there is a strong level of correlation or linear relationship between the explanatory variable and response variable. It also implies that null hypothesis defined is within acceptable limit. The standard error, 89.75 is larger than the coefficient of the predictor (number of pass) which is -49.29 units. On the average, the observed value of the predictor falls 89.75 units from the regression line.

Table 6. *Summary Output.*

	df	SS	MS	F	Significance P
Regression	1	68014.29	68014.29	8.444484	0.033557864
Residual	5	40271.43	8054.286		
Total	6	108285.7			

($Y = \beta_0 + \beta_1 X_1$)	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept(β_0)	295.7143	75.84894	3.898727	0.011424	100.7383863
No. of pass (β_1)	-49.2857	16.96034	-2.90594	0.033558	-92.88365078

Table 6 shows the analysis of variance (ANOVA) of the regression statistics. From the table (Table 6), it can also be inferred that the number of independent variables in the model is 1 as regression degree of freedom *(df)* is 1 while total df is 6. F value in the table is 8.44 and the Significance F is 0.0336. The F value assists in testing the hypothesis that the slope of the independent variable is zero. The significance F is otherwise called the p value for the null hypothesis. It assists in confirming that the coefficient of the independent variable is zero. Since the p-value is below 0.05, it implies there is 95% confidence that the slope of the regression line is not zero. Hence, there is significant linear relationship between number of pass and extraction volume of the fruit juice (watermelon). For individual p-value in table 6, it can be inferred that the predictor (number of pass) is statistically significant – meaning the predictor is applicable for the model.

Figure 7. *Screw juicer evaluation exercise.*

Figure 7 shows the picture of the materials used during the evaluation exercise of the screw juicer. Electronic scale was used to measure fruits before extraction process and juice after extraction process. The outlet for juice is beneath extraction barrel while pulp outlet is at the peripheral of the machine. The machine has comparative advantages over manual extraction of juice as it is less stressful to operate and economical to maintain. It has an extraction capacity (average of 10 liters in 1 hour for watermelon) that can meet the daily dietary requirements (400 g per person, an equivalence of 380 ml) of more than 4 households recommended by nutritionists, if operated for 1 hour (WHO, 2021 and FAO, 2022). If the machine is operated for 8 hours, it can meet the daily needs of an average of 32 households.

CONCLUSION

Screw juicer was developed in this study for small scale processing of fruits into juice. The machine developed was made of stainless steel of 2 mm thickness to avoid food contamination, corrosion of parts and eventual machine failure while in use for extended period of time. The machine performance was evaluated using different types of fruits for process optimization. The juicer gave the highest extraction capacity of 10.48 liters in one hour when watermelon was processed. With cucumber, lowest extraction capacity was recorded (5.08 L h^{-1}). The machine has highest extraction efficiency (79.03%) when orange fruit was processed; the lowest recorded was 48.65% for cucumber.

More effort should be made to encourage fruits and vegetable farmers at all levels in the country to increase production and create awareness on the need to consume more fruits and vegetables as recommended by WHO to meet daily dietary needs recommended by nutritionists. The habit of value addition should also be encouraged amongst farmers and processors in fruit juice industry. The product (fruit juice) should be made more economically accessible to consumers, while generating economic benefits in line with Sustainable Development Goals.

In view of government policy on local production of arable crops to ensure food security and sufficiency, heavy investment on mass production of the machine is recommended for small scale processing of fruits into juice.

DECLARATION OF COMPETING INTEREST

We hereby declare that we have no conflict of interests

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Muyiwa Abiodun Okusanya conceptualized this project, did investigation, design and fabrication of the machine.

Francis Ehis Agbongiaban contributed to the methodology, data collection/analysis performance evaluation review and editing of the write-up.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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