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Development of Modified Manually Operated Fruit Juice Extractor

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ABSTRACT

This paper presents the development of a modified manually operated fruit juice extractor. The modifications were made by developing a power cylinder which can be opened for washing operation and other activities without disassembling the whole system, introducing a U-shaped container to serve as collection chamber, increasing the number of perforations through which the juice drain into the collection chamber and reducing the machines' cost of production. To develop the open-able power cylinder, the stainless steel pipe used for constructing it was sectioned horizontally into two equal parts and angle irons were welded to the edges to prevent leakage and keep the sectioned parts joined. To reduce the cost of production, the machine was produced by the reutilization of locally available materials. When tested for fresh water melon, orange and pineapple fruits, results showed that the average juice yields were 70.05%, 58.16% and 60.20% respectively. The extraction efficiencies were 75.82%, 73.08% and 73.75% respectively. The extraction losses were 1.5%, 4.0% and 1.7% respectively. The machine is simple to operate, easy to maintain and cheap to construct. The cost of producing the machine was N19,850 which makes it affordable for small scale farmers and industries in rural communities.

1. INTRODUCTION

Fruits can be defined as ripened ovaries of plants containing seeds (Aviara et al., 2013). They can be sweet or sour and are edible in raw state. Fruits are important sources of nutrients and components of a healthy diet which helps in preventing major diseases such as cardio vascular diseases (CVDs) and certain cancers (Eyeowa et al., 2017).

In Nigeria, fruits production can be estimated at hundreds of thousands of metric tons per year (Olabisi and Adelegan, 2019). Unfortunately, over 50% are susceptible to spoilage due to their high moisture content and poor post-harvest handling (Adebayo et al., 2014). In order to lessen the deterioration stated above, extracting juice out of fruits is a practical choice.

Juice extraction is the process by which the liquid portion of the fruit is being squeezed or forced out of the solid part by either manual or mechanical means (Adonis et al., 2016). Several researchers have gone into the design and fabrication of machines that can extract juice from various fruits. Some of the machines were manually operated while others are mechanically driven. The machines are of various types based on the materials they were made from, their working principle and capacities. Aviara et al. (2013) developed a motorized multi-fruit juice extractor with a shaft made of iron. The highest percentage juice yield and efficiency recorded for an unpeeled watermelon were 89.7% and 97.17% respectively. Eyeowa et al. (2017) developed a manually operated fruit juice extractor with a polytetrafluoroethylene (PTFE) made screw conveyor to compact and crush fruit. The highest percentage juice yield and efficiency recorded for a peeled watermelon were 57% and 71.3% respectively. Omoregie et al. (2018) designed and fabricated a juice extractor. The machine had a shaft, hopper, press cage housing and press cone made from stainless steel. The highest value of efficiency found was 76.32%. Odewole et al. (2018) developed a manually operated multipurpose fruit juice extractor that has two main parts; the extraction chamber and the structural frame. The extraction chamber was constructed using stainless steel, and consist of a turning handle, screw rod, compression plate, perforated inner cylinder, non-perforated outer cylinder and discharge pipe. The structural frame was constructed using mild steel of angle cross section. The highest value of juice yield and efficiency for a pineapple fruit were 68.74% and 82.99% respectively. Ololade et al. (2018) designed a small-scale motorized bitter leaf juice extractor powered by a 0.3hp electric motor. The machine consisted of a feeding hopper, end plate, worm shaft, juice sieve, juice collector, waste collector, transmission belt, main-frame, pulleys and bearings. The result showed that the average juice yield and extraction efficiency were 77% and 97.1% respectively. Oluwaseun et al. (2018) designed and constructed a motorized citrus juice extractor for small and medium scale industry with shaft and frame made from stainless steel and mild steel respectively. The production cost of the machine is about N117,800. The highest percentage of juice yield was 46.09% for a peeled orange. Aderinlewo et al. (2018) designed and fabricated a motorized juice extractor. The major components of the extractor include the hopper, slicing chamber, extracting chamber frame and outlets for juice and pulp. The highest value of juice yield and efficiency were 51.43% and 83.94% respectively for a pineapple fruit. The cost of producing the machine is N58, 130.

Most of the fruit juicers produced earlier are not easy to operate because the power cylinder cannot be opened without disassembling the whole machine, and the cost of producing them is relatively high. To meet these demands, this study modified an existing machine by redesigning and fabricating it using superior materials available in excess. The study focused on the reutilization of locally available materials. The power cylinder was fabricated using a DC borehole pump casing (a stainless steel cylinder with the required perforations on it) while the screw conveyor was fabricated by rolling a stainless steel rod (from staircase railings) around a motorcycle fork tube.

2. MATERIALS AND METHODS

2.1. Design Consideration

Engineering properties of processed fruit that are relevant to the design, development and performance evaluation were considered. The properties include moisture content, size and shape of the feed, true and bulk densities. Other factors considered are rigidity of materials for machine components, cost of production, ease of inspection and serviceability.

2.2. Material Selection

According to Khanna, (2014), Table 1 presents the machine components, material selected for each component and reasons for selecting the materials.

Table 1: Material selection for the modified fruit juice extractor

Machine components	Material selected	Material specification	Reasons for selection
Hopper & collection Chamber	Stainless steel sheet	2 mm thick	Prevents rust and corrosion resistant
Power cylinder	Stainless steel pipe	External casing of DC deep well submersible pump, AISI304L	Good wear resistance properties, corrosion resistant and prevents rust
Screw conveyor	Stainless steel tube and stainless steel rod	Motorcycle fork tube AISI304 and stainless steel rod used in staircase railings AISI304	Reliability, corrosion resistant, good wearing properties
Shaft	Mild steel	25.4 mm diameter	High fatigue strength, creep resistant, readily available and cheap
Bolts and nuts	Mild steel	M10 grade 8.8	Creep resistant, readily available and cheap
Bearings	Pillow bearing	UCP206	Accurate performance under fluctuating loads and speed
Frame	Low carbon steel of angle cross section	Q235	High strength, excellent machinability and readily available

2.3. Design Calculations

The assumptions made during the design of the modified juice extractor include:

i. the speed at which the screw conveyor was operated was taken to be 60 rpm
ii. the power requirement of a manually operated machine is one seventh a horse power i.e., approximately 107 W as adopted from Aye and Ashwe, (2012) cited in Eyeowa et al. (2017).

2.3.1. Design of the screw conveyor

The screw shaft is the squeezing and conveying part of the machine. It was fabricated using stainless steel and its diameter was obtained using the expression given by Khurmi and Gupta, (2008) as:

$$d^3 = \frac{16}{\pi\Gamma}\sqrt{(K_bM)^2 + (K_tT^2)} \tag{1}$$

Where d = diameter of the screw shaft in m, Γ = allowable shear stress, K_b = combined shock and fatigue factor applied to bending moment, K_t = combined shock and fatigue factor applied to torsional moment, M = bending moment and T = maximum torsional moment.

Since similar method and materials were used to fabricate this projects' screw conveyor with that of Kadurumba and Ogundu, (2020), the values of the variables in Equation 1 were adopted from their research work and were given as:

$\Gamma = 55 \times 10^6$ N/m^2 for shaft without keyway, $K_b = 1.5$, $K_t = 1.0$, M = 0.4440 kNm, T = 5.41 Nm.

Therefore, the ideal diameter obtained was 39.3 and a screw shaft of 40 mm was selected to ensure satisfactory strength and rigidity during operation.

2.3.2. Design of the first pitch of the decreasing pitch auger

According to auger flighting design considerations and nomenclature presented in EP389.1 (ASAE, 1993) cited in Kadurumba and Ogundu, (2020), 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 screw conveyor was obtained using the expression given by Kadurumba and Ogundu, (2020) as:

$$P_s = 1.4D_s \quad (2)$$

Where P_s= first pitch of the decreasing screw conveyor, D_s= Outside diameter of the screw conveyor. Hence P_s= 56 mm.

2.3.3. Design of the pitches of the decreasing pitch screw

The screw conveyor was designed to have 9 pitches of decreasing order. Iteration was used to determine the pitches. A value was assumed in order to obtain the inlet velocity value (v) for the first pitch (P(x)) and then evaluate the remaining 6 pitches using iteration. The summation of the seven pitches must not be greater than the total length of the screw conveyor. The inlet velocity was determined using the equation given by Gbabo et al. (2013) as:

$$P(x_n) = \frac{4VDL}{\frac{\pi}{4}(D^2-d^2)N} \quad (3)$$

Where; $P(x_n)$ = n^{th} pitch, V = inlet velocity of material, D = outside diameter of the screw conveyor, d = inner diameter of the screw conveyor, L = length of the screw conveyor, N = speed of the shaft.

Substituting the available data obtained from Equations 1 and 2 (L = 360 mm, D = 40 mm, d = 0 mm and P_1= 56 mm) into Equation (3), V is found to be 0.073 m/s.

To determine the second pitch ($P(X_2)$) the length L was obtained by subtracting the first pitch out of the total length L_2= 0.36 – 0.056 = 0.304 m

Using the iteration process, the pitches and lengths found were:

L_3= 0.257 mm, L_4= 0.217 mm, L_5= 0.183 mm, L_6= 0.155 mm, L_7= 0.131 mm, L_8= 0.111 mm, L_9= 0.094 mm, P_3= 0.04 mm, P_4= 0.034 mm, P_5= 0.028 mm, P_6= 0.024 mm and P_7=0.02 mm, P_8=0.017 mm, P_9= 0.015 mm.

2.4. Description of the Modified Juice Extractor

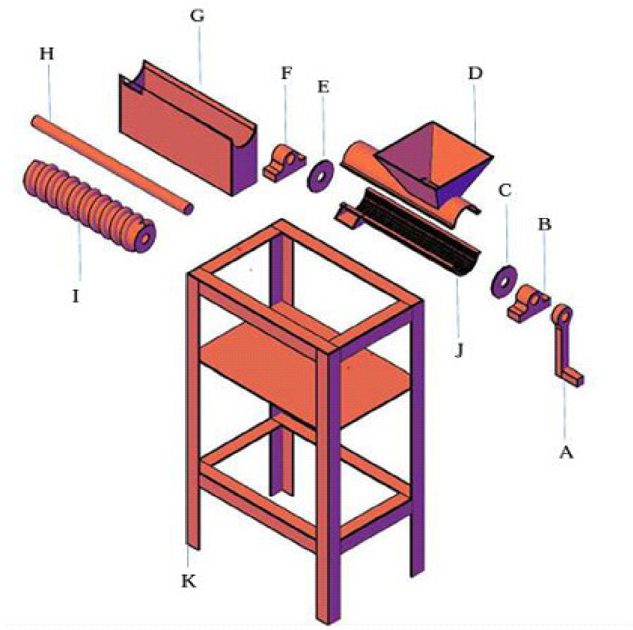
Figure 1 shows the exploded assembly of the modified juice extractor. Careful selection of materials for each part was ensured in order to achieve the goals. The machine is made up of four units; the feeding hopper, processing, collecting and supporting units.

Feeding hopper: The hopper is the only part of the feeding unit; it is the part that retains fruits that are going to be processed. The hopper was constructed using a 2 mm thick stainless steel in a trapezoidal shape. The upper part of the hopper has a dimension of 200×100 mm while the lower part has a dimension of 100×70 mm. The lower part is attached to the power cylinder of the processing unit.

Processing unit: The processing unit comprises the power cylinder, screw conveyor and the shaft. A stainless steel pipe (external casing of a DC deep well submersible pump) of 76.2 mm external diameter and 365 mm length with tiny perforations of 2 mm diameter was used to construct the cylinder. The pipe was sectioned horizontally into two equal parts and all the perforations were placed in the lower section so that the extracted juice will drain into the collection chamber. The power cylinder has an opening towards its end to allow the chute pushed by the screw conveyor go out through the chute outlet. The screw conveyor was constructed by rolling a 10 mm diameter stainless steel rod around a 40 mm diameter stainless steel tube. The screw conveyor made has a length of 360 mm, 10 mm depth, and 7 worms with decreasing pitch. Mild steel rod of 25.4 mm external diameter was used as the shaft.

Collecting unit: The collection chamber is the only part of the collecting unit and it was constructed using a 2 mm thick stainless steel sheet.

Supporting unit: The supporting unit comprises the frame and pillow bearings mounted on it. Low carbon steel of angle cross section with the height of 760 mm and 460×310 mm cross section was used to construct the frame.



LABELS	PART NAME
A	HANDLE
B & F	PILLOW BEARINGS
C & E	CYLINDER COVERS
D	HOPPER
G	COLLECTION CHAMBER
H	SHAFT
I	SCREW CONVEYOR
J	PERFORATED LOWER PART OF THE CYLINDER
K	FRAME

Figure 1: 3D computer aided design model of the modified juice extractor

2.5. Principle of Operation of the Modified Juice Extractor

The machine operates based on the principle of manual rotation of its handle. Whenever peeled sliced fruits are fed into the hopper, the manual rotation of the handle will convey them to the power cylinder where they are squeezed and compressed in order to remove the moisture content in them. The extracted juice drains out of the power cylinder through the perforations on its lower section while the chute is pushed toward the outlet at the extreme end of the power cylinder by the screw conveyor.

2.6. Fabrication Process

Figure 2 and Table 2 give a detailed explanation of the machines' fabrication process. While Table 2 shows the procedures followed in the production of the various components of the machine in addition to the tools and materials used, Figure 2 shows the orthographic view of the modified juice extractor with the dimension of its various components.

Table 2: Results of the fabrication process for the modified juice extractor

Component	Material used	Procedure	Tools used
Hopper	Stainless steel	The work piece was cut into four pieces of the required dimensions and welded to form the hopper	Grinding machine, hammer, arc welding machine
Power cylinder	Stainless steel	The work piece was sectioned horizontally and all the perforations on it were placed in the lower part of the cylinder. Low carbon steels of angle cross section were attached to the sectioning point	Drilling machine, arc welding machine, hammer, grinding machine, filing machine
Screw conveyor	Stainless steel	A stainless steel rod was heated and rolled around stainless steel tube. The pipe was then welded on the tube using arc welding	Arc welding machine, grinding machine, filing machine, hammer
Collection chamber	Stainless steel	The work piece was cut into four pieces of the required dimensions and welded to form the collection chamber	Arc welding machine, grinding machine, filing machine, drilling machine, hammer
Frame	Low carbon steel of angle cross section	The work piece was cut into eight pieces of the required dimensions and welded to form the collection chamber	Arc welding machine, grinding machine, filing machine, drilling machine, hammer

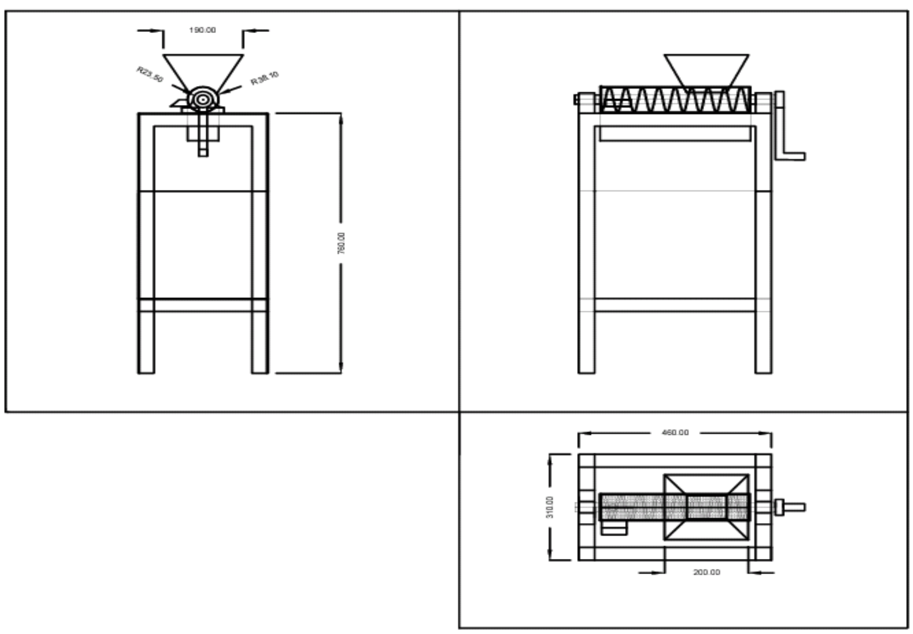


Figure 2: Orthographic view of the modified juice extractor

2.7. Performance Evaluation

After completing the construction of the modified juice extractor as shown in Figure 3, the machine was evaluated based on the report by Odewole et al. (2018) using the percentage juice yield, extraction efficiency and extraction loss as indices.

$$\text{Juice yield} = \frac{100Wje}{Wje+Wrw} \quad (4)$$

$$\text{Extraction efficiency} = \frac{100Wje}{XWfs} \quad (5)$$

$$\text{Extraction loss} = \frac{100(Wfs - [Wje+Wrw])}{Wfs} \quad (6)$$

Where, Wje = mass of juice extracted (g), Wrw = mass of residual waste (g), Wfs = mass of feed sample (g) and X= juice constant of fruit (decimal)

Figure 3: Photograph of the modified juice extractor

2.8. Cost of Production

The machines cost of production is presented in the Table 3.

Table 3: Bill of engineering measurement and evaluation of a unit of the machine

S/N	Material	Specification	Quantity	Unit cost (N)	Total cost (N)
1	Angle iron	2 mm thick	2	1500	
2	Stainless steel sheet	2 mm thick	¼	8000	
3	Pillow bearing	205	2	1200	
4	Bolts and nut	17	4	100	
5	Fork tube	40 mm diameter	1	500	
6	Shaft	25.4 mm diameter	1	450	
7	Stainless steel pipe	76.2 mm diameter	1	800	
8	Paint	Blue	1 cup	300	
9	Paint	Ash	1 cup	500	
10	Labor			3000	
		Total			19850

3. RESULTS AND DISCUSSION

Fresh watermelons, oranges and pineapples were purchased, peeled and sliced. One kilogram each of the sliced fruits was diced into the hopper and the machine was operated. The machine extracts juice from the sliced fruits and both the residue and juice collected were weighed. The juice constants used were adopted from Aviara et al. (2013) and they are 0.8, 0.78 and 0.91 for peeled pineapple, orange and watermelon respectively. Upon testing machine, the results obtained are shown in Figure 4. The average juice yield, extraction efficiency and extraction loss are presented in Figure 4. The juice yield obtained ranged from 58.16 – 70.05%. Water melon has the highest fruit yield which was 70.05% followed by pineapple with

60.21% and orange which had 58.16%. The extraction efficiency ranges from 73.08 – 75.82%. The highest extraction efficiency was obtained from water melon with 75.82% followed by pineapple with 73.75% and orange with 73.08% respectively. The extraction loss ranged from 1.5 – 4.0% with the highest in orange 4.0% followed by pineapple with 1.7% and orange with 1.5% respectively. These values compare favorably with the findings of Eyeowa et al. (2013) as shown in Table 4.

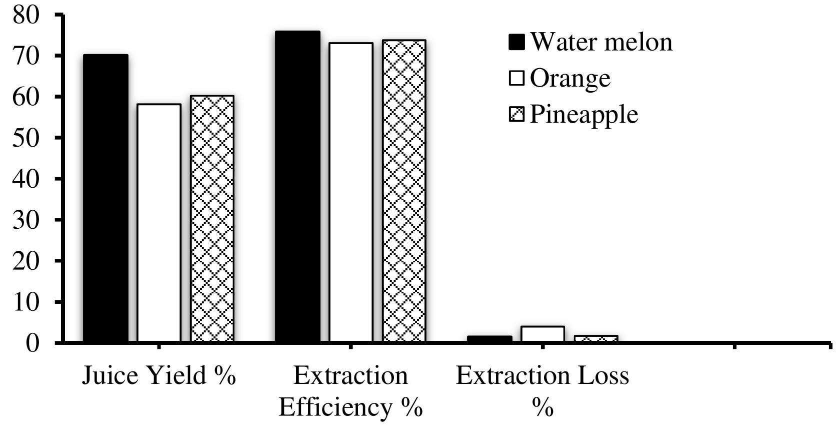


Figure 4: Results obtained after testing the machine

Table 4: Comparing the results obtained from the modified juice extractor with that of Eyeowa et al. (2017)

Evaluation	Fruits used while testing the machine	Percentages obtained	
		Modified fruit juice extractor	Eyeowa et al. (2017)
Juice Yield	Pineapple	58.16	52.9
	Orange	60.20	53.6
	Water melon	70.05	57.0
Extraction efficiency	Pineapple	73.08	63.8
	Orange	73.75	65.8
	Water melon	75.82	71.3
Extraction loss	Pineapple	1.70	3.5
	Orange	4.00	4.3
	Water melon	1.50	2.5

4. CONCLUSION

The development of modified manually operated fruit juice extractor was carried out and tested. The machine served the intended purpose as it was highly cost effective (when compared with the previously produced ones) and easy to operate. The performance of the machine was evaluated, and results obtained show that the machine has an average juice yield of 70.05%, 58.16%, 60.20% and an extraction efficiency of 75.82%, 73.08%, 73.75% for water melon, orange and pineapple respectively. Comparing the results obtained from this machine with that of the ones produced earlier, this machine has higher extraction efficiency and capacity giving it higher advantage with respect of juice extraction efficiency, simple operating mechanism and less cost of production.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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