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RESEARCH ARTICLE

Design and Construction of a Small-scale Motorized Bitter Leaf Juice Extractor

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ABSTRACT

A small-scale motorized bitter leaf juice extractor was designed and fabricated, using locally available construction materials. The essential components of the machine include feeding hopper, end plate, worm shaft, juice sieve, juice collector, waste collector transmission belt, main frame, pulleys, and bearings. In operation, the worm shaft conveys, crushes, presses, and squeezes the herb to extract the juice. The juice extracted is filtered through the juice sieve into the juice collector while the residual waste is collected through the end plate. The result showed that the average juice yield and juice extraction efficiency were 77% and 97.1%, respectively. The machine is powered by a 0.33 hp electric motor; the machine has a capacity of 35.4 g/min. It is affordable for small-scale farmers and industries in rural communities.

Key words: Bitter leaf, construction, design, juice extractor, juice yield, small-scale motorized

INTRODUCTION

The herb known as the bitter leaf is a shrub or small tree that can reach 23 feet in height when fully grown. Bitter leaf has a gray- or brown-colored bark; the bark has a rough texture and is flaked. The branches of the shrub are brittle and break off easily. The green leaves are oblong to lance like a shape, they are veined and bear pale soft hairs on the underside. Bitter leaf bears small white flowers; these flowers bloom in clusters during the spring.[1] Bitter leaf is derived from the leaves of a small evergreen shrub found all over Africa called *Vernonia*, belonging to the family Asteraceae. *Vernonia amygdalina* is a widely known plant popularly called bitter leaf, evergreen in nature and flourishes wherever it grows. It is called "ONUGBU" by the Igbos of the eastern part of Nigeria who uses it as vegetables and "EWURO" by the Yorubas of the western part of Nigeria who uses it for medicine, while the Hausas of Northern Nigeria call it "SHIWAKA."[2] *V. amygdalina* is popular for its bitterness, its leaves, stem, roots, and bark; a little reminder that life is not all sweetness, therefore, the slang name BITTER LEAF.

Bitter herbs help to tone vital organs of the body such as the kidney and liver. The liver is the largest organ in the body and is responsible for the secretion of bile and formation of glycogen. It is also responsible for the metabolism of protein and fat, in fact, its an organ anyone would want to keep intact because once there is a defect it is very hard to correct. The kidney helps expel waste materials from the body; a breakdown of the kidney is a general disorder of the entire body. The bitter leaf contains vernodalin, venomygdin, and saponin which are antibacterials that help keep this vital organs (kidney and liver) in order.[2] True to its name, this leaf is bitter to taste, but surprisingly delicious in meals. The leaf can be eaten fresh-like spinach in soup or dried too.

African cuisines featuring this leaf as ingredients include Ogbono soup, Okra and bitter leaf soup, pepper soup, bitter leaf soup (Ndole in Cameroon), and Banga soup. In many parts of West Africa, the leaves are used to wash slime of fish and snail been cooked. The roots and twigs are eaten as appetizer too. These leaves have great nutritional, herbal, and medicinal value. It contains very high amount of zinc, important in many enzyme

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functions and keeping the skin fresh. They also contain saponins and tannins (glycosides), as well as alkaloids. At least 13 other new compounds or vital ingredients have been found in these leaves, after 40 years of study and have the following benefits: Antibacterial, antimalaria, antiparasitic, and anticancer. It is also effective in preventing indigestion, scurvy, sciatica, and rheumatism.[2] At least 30 different illnesses have been suggested to be curable with the use of bitter leaf herbs.[2]

In most developing countries, the extraction of bitter leaf (*V. amygdalina)* juice is still based on traditional procedures involving squeezing or rubbing the leaf by hand or pounding with mortar and pestle to obtain the juice. The traditional methods are unhygienic, tedious, and time consuming. Bitter leaf is highly perishable in its natural state after harvest and is vulnerable to spoilage by mechanical damage, chemical deterioration, and environmental effects. Thus, it is highly essential to process the freshly harvested vegetable into juice which can be consumed freshly or processed further for healthful beverages. Therefore, the objectives of this study are as follows: To design and develop an easy to operate and affordable machine that can extract juice from bitter leaf, fabricate the machine with locally source materials and to test its performance and efficiency.

MATERIALS AND METHODS

Design concept

Every machine operates on two basic philosophy, that is, the comfort and ease at which the machine can be used and "man" in relation to the working of that machine.

The method adopted in the design of the bitter leaf juice extractor is the screw press mechanism. The major components of the bitter leaf juice extractor are as follows: Hopper, rotating disc (shredding unit), screw press, juice outlet, end plate, frame, and prime mover (electric motor).

Design consideration

The knowledge of properties of the engineering materials is of great significance to a design engineer. The machine components should be made of such materials which have properties suitable for the operating conditions. Besides, effects which the manufacturing processes and heat treatment have on the properties of the materials must be well known. Selection of the most suitable material for a given component is one of the greatest challenges in engineering design, as such careful and enduring attention was exercised to ensure that material chosen for a given element is one which serves the desired objective at the maximum cost.

Factors that were considered in the choice of materials are as follows: Availability of the material, suitability of the material for the working conditions in service, the cost of the material, portability and weight reduction, and steel contamination. The important properties which determine the utility of the material are its physical, chemical, and mechanical properties.

The physical properties of the material include luster, color, size and shape, density, electric and thermal conductivity, and melting point.

The mechanical properties of the material are its strength, stiffness, electricity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep, and hardness. While the material chemical properties reveal among others, its ability to resist corrosion.

Material selection

Materials Selection is given in Table-1 Summary of material selection.

Design analysis and calculations

Design of the hopper

The squared shape hopper feeds in vegetable to the cylinder by gravity with 1.6 mm stainless steel plate, the volume of the hopper occupied by the steel is 1.4×10^{-4} m^3; therefore, the weight was obtained as 2.24 kg.

Design of the cylinder

The cylinder was fabricated from 1.6 mm galvanized steel sheet to 45 mm diameter and 100 mm length. The squared feed hopper sits on a 400 mm × 40 mm opening 100 mm from the drive end of the cylinder. The volume of the cylinder is 2.09×10^{-4} m^3. The weight was calculated as 9.4 kg.

Design of the power screw of the extraction unit

The model used for the design of the power screw of the extraction unit was given by Shigley and

Mitchell[3] as follows:

$$d_w^3 = \left[\frac{16}{\pi s_s}\left(K_b M_b\right) + \left(K_1 M_1\right)^2\right]^{1/2} \quad (1)$$

Where,
d_w is the diameter of the power screw
M_b is the bending moment of the shaft
M_t is the torsional moment of the shaft
K_t is the combined shock and fatigue factor for torsion
K_b is combined and fatigue factor for bending and
Ss is the maximum shear stress.
d_w = diameter of the worm shaft (screw press), given that M_b = 6.473 Nm and M_t = 39.306 N_m; hence, d_w = 19.734 mm.
A stainless steel rod of diameter 25 mm was used for the worm shaft (screw press).
The pitch of the screw of the worm shaft (screw press) was determined by the equation given by Shigley and Mitchell[3] as follows:

$$P_w = \pi \tan\varphi \, d_{wm} \quad (2)$$

Where,
P_w is the screw pitch,
d_{wm} is the mean diameter of the worm shaft and φ is the lead angle.
Given that, d_{wm} = 33.50 mm and φ = 100;
Hence, P_w = 18.56 mm.
Therefore, a screw system of uniform pitch is the developed extraction unit.

Design of the spike shaft of the shredding unit

The model used for the design of the spike shaft of the shredding unit was proposed by Khurmi and Gupta[4] as follows:

$$d_S{}^2 = \left[\frac{16}{\pi s_s}\left(K_b M_b\right) + \left(K_1 M_1\right)^2\right]^{1/2} \quad (3)$$

Where, d_s is diameter of the spike shaft, S_s is maximum shear stress, K_b is combined and fatigue factor for bending, K_1 is combined shock and fatigue factor for torsion, M_b is bending moment of the shaft, and M_t is torsional moment of the shaft.
Given that, $S_s = 40 \times 10^6$ N/m^2, K_b = 2.0, K_t = 1.5 *Mb* = 11.292 Nm, *Mt* = 19.755 Nm and π = 3.142; hence,
d_s = 16.152 mm
The pitch of the helix formed by the teeth arrangement of the spikes on the spike shaft was determined by the equation given by Shigley and Mischke[3] as follows:

$$P_s = \pi \tan\varphi \, d_{wm} \quad (4)$$

Where, P_s is the spike pitch, d_{sm} is the mean diameter of the spike, and φ is the lead angle.
Given that, d_{sm} = 225 mm and φ = 100; hence, P_s – 124.65 mm

Design for the number and spacing of spikes on the shaft

The model used for the design of the number of spacing of spikes on the shaft was determined by the expression given by Shigley and Mischke[3] as follows:

$$S_n = \frac{Is}{St} \quad (5)$$

Where, S_n is number of spikes on the shaft, *Is* is length of spike shaft, and *St* is the desired thickness of lump (spacing of spikes). Given that, *Is* = 600 mm and *St* = 20 mm, hence, S_n = 30.
Therefore, 30 spikes each of length 200 mm, width 30 mm, and thickness 2 mm.

Design for the capacity of the machine

The model used for the design of the coping capacity of the machine is a modified form of the equation given by Onwualu *et al*.[5] as follows:

$$Qc = 0.060\frac{\pi}{4}\, D_S^2 - d_S^2 \, P_S \, N_S \varnothing p \quad (6)$$

Where, *Qc* = the shredding capacity of the machine, *Ds* = the spike diameter, *Ns* = the rotational speed of the spike shaft, ∅ = filling factors, and *ρ* = density of bitter leaf substituting *Ds* = 425 mm, d_s = 25 mm
Ps = 125 mm, *Ns* = 725 rpm, ∅ = 0.25, and *ρ* = 964.5 kg/m^3 into the above equation, then *Qc* = 185.379 kg/s.
The extraction capacity was determined using a modified form of the equation given by Onwualu *et al.*[5] as follows:

Table 1: Summary of material selection

Machine, components	Manufacturing material
Hopper	Galvanized steel
Shredding unit	Stainless steel
Extraction unit	Stainless steel
Juice outlet	Stainless steel
End plate	Galvanized steel
Frame	Gray cast iron
Prime mover motor stand	Electric motor
Frame	Gray cast iron

$$Qc = 60\frac{\pi}{4}D_w^2 - d_w^2 P_w N_w \varnothing P \quad (7)$$

Where, Qe = extraction capacity of the machine D_w screw diameter, N_w is the rotational speed of the worm shaft, $\varnothing$ = filling factor, and ρ = density of bitter leaf. Given that, D_w = 42 mm, d_w = 25 mm, P_w = 20 mm, N_w = 362.5 rpm, $\varnothing$ = 0.25, and ρ = 946.5 kg/m^3, hence, Qe = 93.843 kg/s.

Design of V-belt drive mechanism

The size of the driven pulley was obtained through its diameter from the following velocity ratio equation given by Sahay (2006); the peripheral velocity (V) of the screw press shaft and the radius (R) of its pulley (driven) were obtained from the equation given by Ahemen and Raji.[6]

$$V = \frac{\pi DN}{60} \quad (8)$$

Where, V is peripheral velocity of the shaft (m/s), D is shaft diameter (mm), and N is speed (rpm) and

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} - \frac{R_2}{R_1} \quad (9)$$

Where, N_1 is the number of revolutions of driving pulley, N_2 is the number of revolutions of driven (drum) pulley, D_1 and R_1 are the diameter and radius of the driving pulley, respectively, and D_2 and R_2 are the diameter and radius of the driven (drum) pulley.

Design for the power requirement of the machine

The power required by the machine for shredding was obtained using equation (10) as given by Onwualu *et al.*[5] as follows:

$$Pc = Q_{VC}\, I_S\, P_g\, F \quad (10)$$

Where, Pc = power required for shredding.
Q_{vc} = volumetric capacity, Ps = diameter of spike shaft, g = acceleration due to gravity and 125 mm, g = 9.8 m/s^2, and f = 0.5, hence, Pc = 113.66 W.
The power required by the machine for extraction was calculated using equation (3.9)

$$P_e = Q_{ve}.\, I_w P\, g\, F \quad (11)$$

Where, P_e = power required for extraction
Q_{ve} = volumetric capacity, Ps = diameter of spike shaft, g = acceleration due to gravity and F = material factor, and I_w = length of worm shaft. Given that, Q_{ve} = 0.0973 m^3/s, I_w = 280 mm, g = 9.81 m/s^2, and F = 0.5, hence, P_e = 138.094 W. Therefore, the total power required of the machine was obtained using equation (12).

$$P_t = P_c + P_e \quad (12)$$

Where, P_t = total power required
P_c =113.66 W, and P_e = 138.094 W; therefore, P_t = 251.754 W.
The power of the electric motor to drive the system was estimated as follows:
Power required of the machine = 251.754 W.

$$P_m = \frac{\pi DN}{60} \quad (13)$$

$$\text{Power of electric motor} = \frac{251.754}{746} = 0.33 \text{ hp}$$

Therefore, the power of electric motor is 1/3 hp.

Power transmission drive

V-belt was employed to transmit power from one shaft to another between parallel shafts.
The V-belts transmit power from the 1/3 hp electric motor to the driving pulley and the driven pulley to the screw conveyor shaft. A V-belt drive consists of an endless flexible belt that transmits power by contacting and gripping the sheaves, which are keyed to the shafts of the driving mechanism and the driven mechanism. The primary reasons for using a V-belt drive are its simplicity and low maintenance costs. The ratio of the driving pulley and driven pulley is 3:1, to reduce the vibration and also to step down the speed of the electric motor a ratio of 3:1 is adopted. For every three revolutions of the smaller pulley the larger pulley rotates once, this is for ease of operation, this agrees with the findings of Olaniyan[7] and Olaniyan and Babatunde.[8]
Proper juice extraction requires separation of the macerated foliage. To reduce the cost of production from the power requirement, this design combines the process of pressing and filtering the extracted juice. This involves the use and proper design of a crew press with a perforated cylinder which agrees with the findings of Oyeleke and Olaniyan.[9] The pressure is provided by the screw which also macerates the foliage and the obstruction created at the exit end enables the system to work like an extruder. The mesh which behaves like a porous media is pressed against the obstruction. The effective parameters of the screw (diameter and pitch) are hose of the inlet which determines the amount of mass flow to extract juice from the leaf. The power required to convey the foliage across the cylinder length (100 mm) and that for compressing the leaves against the plate, assuming

that the power required for the compression against the wall of the cylinder is negligible.

Description of the extractor

The hopper is located at the top of the machine [Figures 1 and 2]. It serves majorly as the channel through which the bitter leaf gets to the extraction unit. The hopper was designed with a 1.6 mm thick galvanized steel sheet, the volume of the hopper occupied by the steel is 1.4×10^{-4} m^3.

The cylinder is made of 1.6 mm galvanized steel sheet to 45 mm diameter and 100 mm length opening 100 mm from the drive of the cylinder. The extraction chamber of the cylinder was perforated.

The shredding unit is made up of a rotator disc with embedded blades. The main function of this unit is to reduce the size of the bitter leaf into smaller pieces, thereby exposing its internal cells for juice extraction.

The screw press is the main component doing the extraction. The screw press conveys, presses, and squeezes the juice out of the bitter leaf, the juice extracted flows out through the perforated part of the cylinder that serves as a serve. The length of the screw press is 280 mm with a diameter 42 mm and screw pitch 18.56 mm. The juice outlet is attached to the extraction cylinder. The juice squeezed off is collected through the juice outlet.

The end plate is made of galvanized steel. The function is to support the compression shaft; it was designed to serve as a collector chamber for the forage or mesh it also houses the obstruction seal to prevent the mesh from coming out from beneath, during juice extraction.

The machine frame bears and supports the machine, it is made of gray cast iron and it is also designed to support the electric motor.

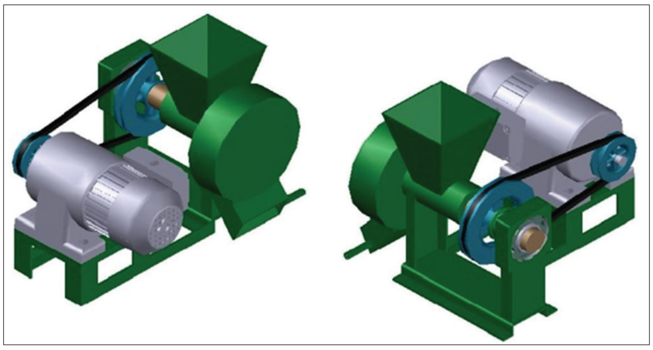
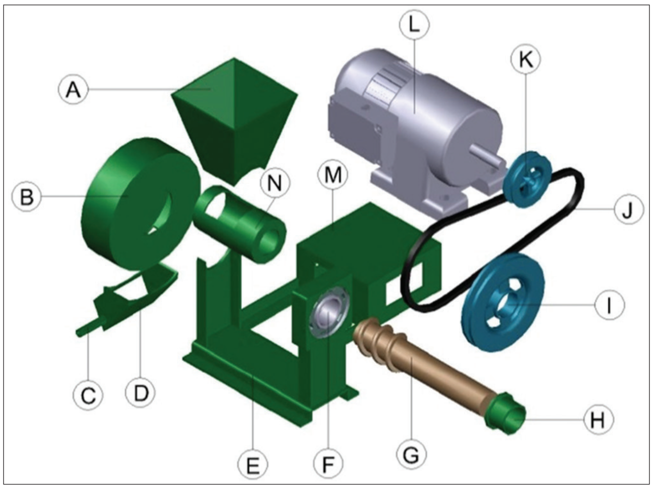


Figure 1: 3-D computer-aided design model of the bitter leaf juice extractor



Part	Description	Part	Description
A	Hopper	I	Machine pulley
B	Shredding unit	J	V-belt
C	Juice outlet	K	Motor pulley
D	Shred outlet	L	Electric motor
E	Base frame	M	Electric motor base
F	Ball bearing	N	Cylinder
G	Main shaft		
H	Stud		

Figure 2: Exploded view of the bitter leaf juice extractor`

Procedures of juice extraction/machine principles of operation

The bitter leaves were fed into the hopper to screw press which conveys it to the shredding unit where it is shredded into smaller (articles exposing the cells for juice extraction, the screw press still rotating, presses the mesh to the conical end of the cylinder where it presses and squeezes out the juice). The end plate has a construction seal that prevents the mesh from coming out at that point [Figure 1].

Below the conical end of the cylinder is perforated and serves as a sieve through which the liquid expressed is filtered and drained from the mesh through the juice outlet where it will then be collected, while the mesh is collected through the end plate which serves as the waste collector and the mesh is coped out on completion of the juicing operation. The operation was repeated for sliced pineapples to test for its suitability for non-leafy products and it was discovered that the machine can be used for both leafy and non-leafy product; hence, one can say that the machine is a multipurpose juice extractor. The machine is powered by 1/3 electric motor with the construction materials being usually available at affordable costs.

Sample preparation/performance test criteria

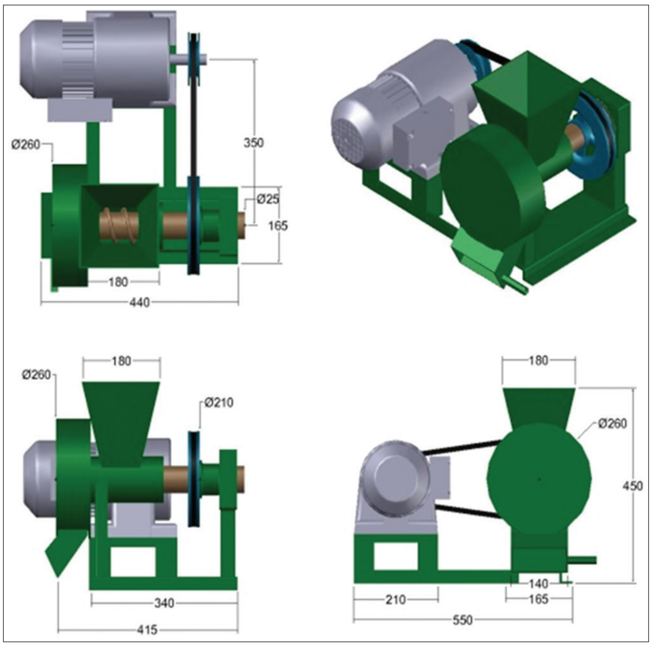


Figure 3: Orthographic view of the bitter leaf juice extractor

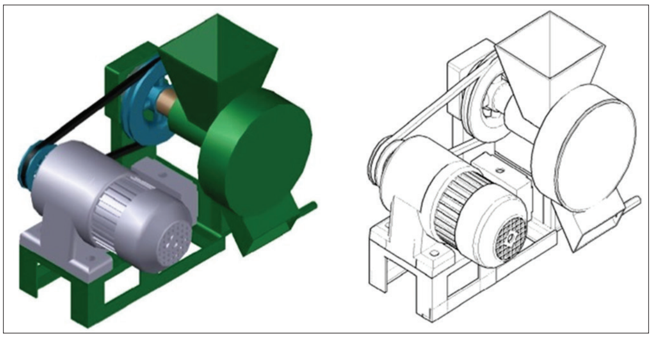


Figure 4: CAD model and isometric view of bitter leaf juice extractor

Samples of bitter leaves were obtained from the local market. In the test, operation attention was paid to the juice yield and efficiency of the machine. Pineapple fruit juice was also extracted in the machine to test its suitability and efficiency for non-leafy products. The performance of the juice extractor was evaluated based on the efficiency of the machine and the percentage yield of juice extracted using the equations below:

$$Efficiency(\%) = \frac{WSAP + WJE}{WSBP} \times 100 \quad (14)$$

Where, $WSBP$ = Weight of sample before pressing, $WSAP$ = Weight of sample after pressing, and WJE = Weight of juice extracted

$$Juice\ yield(\%) = \frac{WJO}{WSBP} \times 100 \quad (15)$$

Where, $WSBP$ = Weight of sample before pressing and WJO = Weight of juice obtained

$$Throughput\ capacity\ (g/min) = \frac{\text{WJO}}{Pt} \times 100 \quad (16)$$

Where, WJO = Weight of juice obtained and Pt = Pressing time [Figures 3 and 4].

RESULTS AND DISCUSSION

Performance of test result

The results for the experiments performance test analysis of the bitter leaf juice extracting machine are presented in Tables 2 and 3.

Therefore, throughput capacity of the juice extractor is 35.4 g/min.

From Table 2, the performance of the machine has 97.1% efficiency in bitter leaf juice extraction and 98.3% efficiency in pineapple juice extraction. This is expected as pineapple has higher moisture content and is softer to compress than bitter

Table 2: Performance of bitter leaf juice extractor

Sample	WSBP (g)	WSAP (g)	WJE (g)	WFLM (%)	MFE (%)
Bitter leaf	890	510	354	26 (2.9)	97.1
Pineapple fruit	900	315	570	15 (1.7)	98.3

WSBP: Weight of sample before pressing, WSAP: Weight of sample after pressing, WJE: Weight of juice extracted, WFLM: Weight of forage left flow in machine, MFE:Material flow efficiency

Table 3: Thorough put of the juice extractor

Sample	WSBP (g)	IMC (%w.b)	FMC %	QJO (g)	WJO (g)	Pt (min)
Bitter leaf	890	56	14.9	39.1	354	10
Pineapple fruit	-	900	-	65.4	570	10

WSBP: Weight of sample before pressing, IMC: Initial moisture content, FMC: Final moisture content, QJO: Quantity of juice obtained = 100% wet weight, WJO: Weight of juice obtained, Pt: Pressing time leaf. The juicing operation was carried out using pineapple to test the machines efficiency in non-leafy products and it was discovered to be effective. This agrees with the findings of Badmus and Adeyemi[10] and Ishiwu and Oluka.[11]

From Table 3, the moisture content of the bitter leaf was initially 56% wet basis. This is in agreement with FAO[12] that stated that grass leaf juice constitutes about 50% of the weight. The initial moisture content reduced to 14.9% wet basis. This shows an extraction of 39.1% wet basis of the moisture present which is equivalent to juice recovery of 77.8% from the juice present before extraction. This is an acceptable level of juice recovery as the presence of about 15% juice in the fiber makes it suitable for consumption as vegetables and can also be used as livestock feed[13-16].

CONCLUSION

All the components of the machine are locally and readily available. Parts that are prone to corrosion and rust were made of stainless steel to enhance longevity. The machine was designed to have minimum labor input; hence, the family sized machine can be operated by one person and can be used by rural farmers, both skilled and unskilled person as the central switch is painted with colors that can be interpreted, red is the turn off switch and green is the turn on switch. Since routine maintenance of both the engine and pressing unit should be carried out regularly, ease of operation and dismantling for maintenance were considered in the design and selection of appropriate joints and couplings. This simply means that joints can easily be decoupled for maintenance and recoupled after maintenance.

It is, therefore, recommended that stainless steel should be used in all parts that come in contact with the juice, further study to increase the efficiency and capacity of the machine to a commercial scale is also recommended.

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