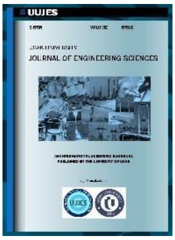

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Research article

DEVELOPMENT OF A MODULAR BITTER LEAF WASHING AND JUICE EXTRACTION MACHINE

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Abstract

Bitter leaf (*Vernonia amygdalina*) is one of the leafy vegetables that can be used to alleviate the problem of malnutrition. To ensure availability in non-growing areas of sub-Sahara Africa, the vegetable needs to be preserved. Processing and preservation methods influence the nutrient content of the vegetables. This research work is therefore focused on the development of a modular bitter leaf washing and juice extraction machine. The machine is an electrically powered bitter leaf juice extractor that washes bitter leaf fed into it and at the same time squeezes out the juice. It uses stainless steel beaters inclined to angle of 0^o to wash and squeeze the leaves against the cylindrical hopper incorporated with a perforated plate that drained juice while pulp is expelled. The beater is designed to work with the principle of oscillatory motion. The designed and fabricated bitter leaf juice washing and extraction machine was evaluated to determine the power, torque, force, etc., that are required to wash and extract the juice. The results obtained showed that the speed reduction, angular velocity, centrifugal force, torque, and power of 0.0127 m^3, 480 rpm, 50.285 rad/sec, 303.430 N, 3.03 Nm, 0.75 hp are required. Also, a minimum bitter leaf extraction time of 398.28 seconds was required by the machine in comparison to manual extraction time of 724.13 seconds. Besides, the result of volume of bitter leaf juice extracted manually and mechanically from 0.40754 kg of bitter leaf were 3.60 litre and 3.63 litre respectively. The efficiency of the machine and the machine throughput capacity were obtained as 55.00 % and 0.001023 kg/sec respectively. This simply implies that the developed machine is 55.00 % efficient than manual method of washing bitter leaf in sub-Sahara Africa.

Keywords: *Bitter Leaf; Washing Machine; Extraction Machine, Modular; Efficiency; Extraction Time.*

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1. Introduction

Bitter leaf (*V. amygdalina*) is a common homestead farming vegetable and fodder tree in sub-Sahara Africa [1,2] and has been used as an ingredient to prepare Nigerian dishes (Ogbono soup, bitter leaf soup, egusi soup, etc.) or Cameroon (Ndole) after removal of its bitter taste through washing in several changes of water or by boiling [1-3]. It is a unique plant (see Fig. 1), so exceptional that every part of it has an economic importance. The leaves have a dimension of 6 mm in diameter and 200 mm long [4], it is dark green and is consumed in a wide variety of delicacies in sub-Sahara Africa countries as depicted.

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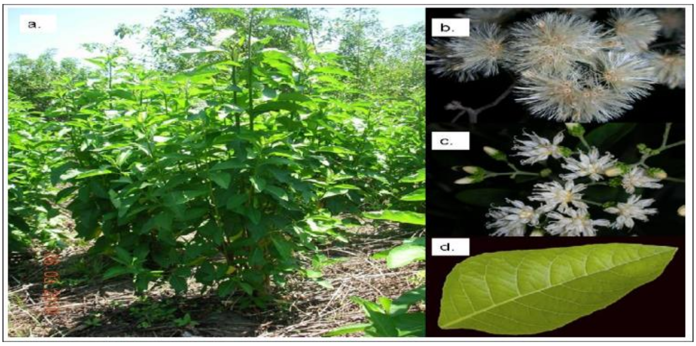


Fig. 1 a. Bitter leaf plant; b. Bitter leaf shrub; c. Bitter leaf flower; d. Leaf of the plant

The leaves of *V. amygdalina* are rich in nutrients such as vitamins, fibre, carbs, and minerals, making them an important part of the human diet [5-6]. Its leaves are macerated and used in cooking soup, while the extracts are used as tonic for prevention of certain illness. It contains significant quantities of lipids [7], proteins with essential amino acids [8]. It also contains carbohydrates [9] and carotenoids, though not in large quantities [10]. Also contained in this plant are essential elements such as calcium, iron, potassium, phosphorus, manganese, copper and cobalt [11]. It is also used by scientists in curing joint pains associated with diabetes, persistent headache, cancer, fever reduction and a host of others [12-15]. It is equally used for treatment of gastro-intestinal problems, malaria, toothache and fertility problems [16-18]. It is also used as digestive tonic, appetizer and febrifuge, and for topical treatment of wounds as a substitute for iodine [19-22].

Since bitter leaf is a crop that is readily available all years round in sub-Sahara Africa countries such as Nigeria, its easy and wide usages will enhance Nigeria's economy, food scarcity, and generate employment for the farmers and youths. Also, the production and processing of bitter leaf juice for local pharmaceutical and for export would lead to an improvement in the health of Nigerian and equally earn foreign exchange for the country. Consequently, in order to make washed bitter leaf readily and cheaply available for domestic use while also producing large volumes of the juice for processing for use by the pharmaceutical industries, the greatest bottleneck in the post-harvest processing of bitter leaf (i.e., washing) needs to be mechanized. As far as it is known in literature, there has been no successful attempt to efficiently and effectively mechanize the bitter leaf washing and juice extraction to avail the country of all the above-mentioned uses, economics and health benefits. However, [23] developed a machine for expressing *V. amygbalina* leaf juice. The design of the machine was based on the principle of a pressure deferential applied to the incoming leaf mesh compared with that applied to the discharged material. Macerated bitter leaves were compressed through a tapered screw conveyor; whose shaft terminates as a rising but short conical kink. The greatest draw back, was that the juice extracted is relatively small and the macerated leaves are not recoverable. Also, there is no effective washing chamber unit, no storage unit, and no requirement to drain the extracted juice. More so, [24] used alcohol as a catalyst for the extraction of bitter leaf (alkahoid) in their final year project work carried out in Department of Mechanical Engineering, University of Benin. However, the alcohol was not recoverable at the end of the washing process. Thereby making the use of the extracted liquid for medicinal, pharmaceutical, brewing operation and industrial purpose unsuitable.

2. Materials and Method

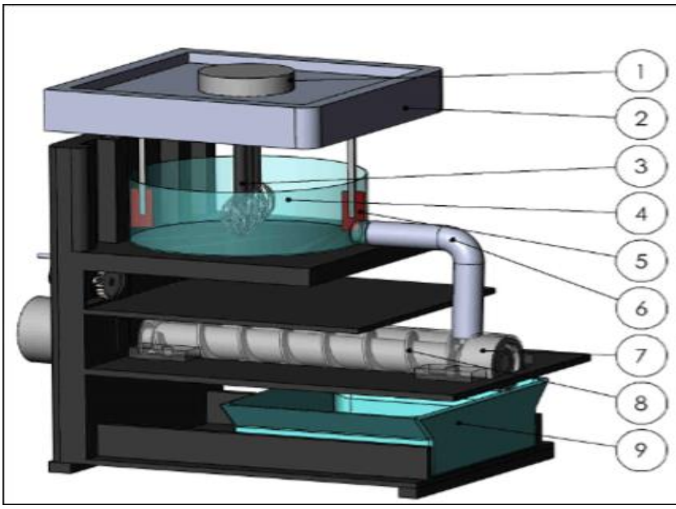
2.1 Experimental Design

To have a better understanding of the propose machine, experiment was carried out using manual method via the use of mortar and pestle in washing and extraction of bitter leaf as shown in Fig. 2. The bitter leaf was washed in clean water. It was crushed into a homogenous powder using mortar and pestle. The crushed bitter leaf sample was soaked in water with intermittent stirring. The aqueous extract was filtered through a 2 mm mesh filter and the filtrate was stored in clean sterile bottles. The time taken to extract the juice was recorded. From the experimental analysis, two conceptual designs were developed. The best concept was chosen for final development based on the following evaluation criteria; performance, cost, manufacturability and safety using decision matrix.

Fig. 2 Manual method for washing and extraction of bitter leaf juice

2.2 Conceptual Design

Two design concepts were considered. Design concept one shown in Fig. 3 uses an electric motor, adjustable head, mixer, conveyor, mixing chamber, rotating blade, etc. The force needed to extract juice from the bitter leaves is applied by the rotating blade attached to the shaft. The rotating blade attached to the shaft conveys the bitter leaves and thus impact a shear force applied on it and in the process crushed it against the wall as it rotates them along. The bitter leaves are prevented from being turned with the rotating blade due to their weight and the friction between them and the walls of the barrel.



ITEM NO.	PART NAME
1	Electric motor
2	Adjustable head
3	Mixer
4	Mixing Chamber
5	Rotating Blade
6	Drain
7	Conveyor case
8	Conveyor
9	Collector

Fig. 3 Isometric view of design concept one

Design concept two as shown in Fig. 4 makes use of an electric motor, a feeding hopper, rotating beater, drain pipe and valve unit, V-belt, shaft, ball bearings, etc. The system is driven by the shafts, and torque is transmitted to the rotating beater via a V-belt attached to a two-way pulley. The beater crusher incorporated in the machine crushes continuously the bitter leaves that are fed in the machine against a metal surface cylindrical hopper. The motion of the rotating beater is achieved using a shaft which is connected to an electric motor by the means of V-belt and pulley. The motion of the driver and driven pulley is such that it converts and transmits the rotating motion of the motor to reciprocating motion of the beater.

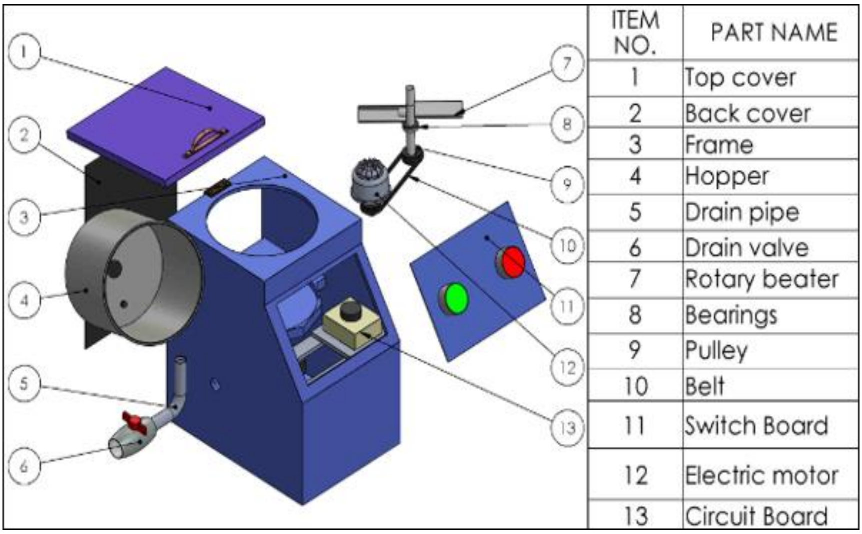


Fig. 4 Isometric view of design concept two

To ensure the best concept was chosen for detail design, a decision matrix was drawn based on the following design considerations; performance, cost, manufacturability and safety. A decision matrix is a list of values in rows and columns that allow an analyst to systematically analyze and rate the performance of relationships between sets of values and information. Each category is assigned a weighing factor base on believe which measures its relative importance. Based on the ranking, design concept two with a ranking of 88 was selected for detail design. Table 1 shown decision matrixes used for selecting the best conceptual design.

Table 1. Decision matrix

		Design Concept 1		Design Concept 2	
Criteria	Weight	Rating	Score (1)	Rating	Score (1)
Performance	4	7	28	8	32
Cost	3	4	12	9	27
Manufacturability	2	4	8	10	20
Safety	1	4	4	9	9
Total			**54**		**88**

*Weight Factors from 1 – 4 and Rating 1 – 10 *Score=Rating x Weight

2.3 Machine Configuration

The isometric view of the modular bitter leaf washing and extraction machine is shown in Fig. 5.

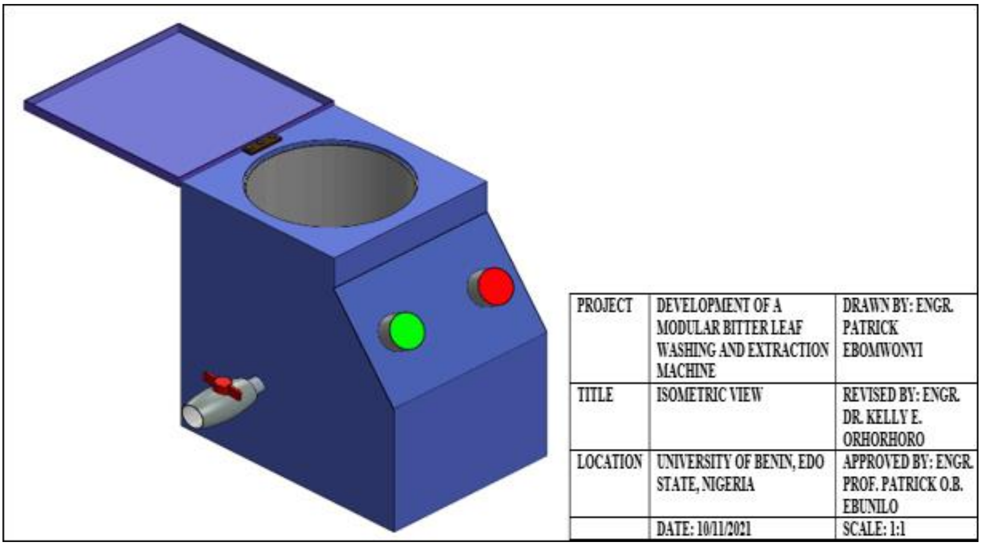


Fig. 5 Isometric view of the modular bitter leaf washing and extraction machine

Fig. 6 shows the fabricated prototype of the modular bitter leaf washing and extraction machine.

Fig. 6 Fabricated prototype modular bitter leaf washing and extraction machine

2.4 Detailed Design

This section built on the already developed concept, aiming to further elaborate each aspect of the project by complete description through mathematical modeling, working drawing as well as specifications. Consider a particle, moving round the circumference of a circle of radius r, with a uniform angular velocity ω (rad/s), as shown in Fig. 7.

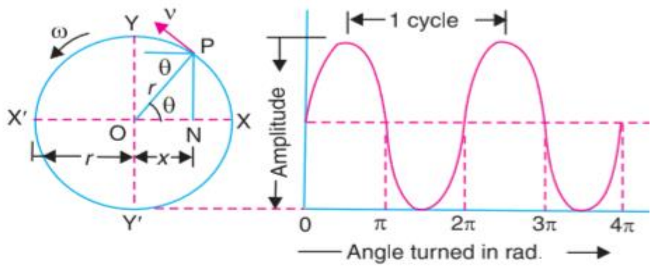


Fig. 7 Velocity and acceleration of a particle in periodic motion

If P is any position of the particle after t (seconds) and θ the angle turned by the particle in t (seconds). Then,

$$\theta = \omega . t \quad (1)$$

Also, If N is the projection of P on the diameter XX ′, then displacement of N from its mean position 0 is given by Equation (2).

$$x = r. cos\theta = r. cos\omega . t \quad (2)$$

The velocity of N (m/sec) is the component of the velocity of P parallel to XX ′ [25].

$$V_N = v. sin\theta = r\omega sin\theta = \omega\sqrt{(r^2 - x^2)} \quad (3)$$

But,

$$rsin\theta = NP = \sqrt{(r^2 - x^2)} \quad (4)$$

More so, the velocity is maximum, when x = 0 (i.e., when N passes through O i.e., its mean position).

$$V_{max} = r\omega \quad (5)$$

Similarly, the acceleration of P is the centripetal acceleration whose magnitude is ω^2.r (rad/sec^2). The acceleration of N is the component of the acceleration of P parallel to XX′ and is directed towards the centre 0. Thus,

$$a_n = \omega^2 . rcos\theta = \omega^2 x \quad (6)$$

Therefore,

$$x = rcos\theta \quad (7)$$

The acceleration is maximum when x = r (i.e., when P is at X or X′).

$$a_{max} = r\omega^2 \quad (8)$$

From Equation (6) and Equation (7), when x = 0, the acceleration is zero (i.e., N passes through 0). Thus, the acceleration of N is proportional to its displacement from its mean position 0, and it is always directed towards the centre 0; so that the motion of N is simple harmonic [25].

Also,

$$v = \frac{\pi DN}{60} \quad (9)$$

But,

$$r = \frac{D}{2} \quad (10)$$

Substitute Equation (5) and Equation (10) into Equation (9).

$$\omega = \frac{2\pi N}{60} \quad (11)$$

A centrifugal force is required by the system and is given by Equation (12);

$$F_c = mr\omega^2 \quad (12)$$

Mathematically, the torque (Nm) is given by Equation (13);

$$T = F_c r \quad (13)$$

The required power by the system is given by Equation (14);

$$P = \frac{F_c \pi DN}{60} \quad (14)$$

The speed reduction was design for and this is to ensure;

i. that power is delivered at lower speed to the crusher mechanism.
ii. that power is transmitted through the machine element that reduces the rotational speed.

The velocity ratio for the belt drive is the ratio between the velocity of the driver and the driven. It may be expressed mathematically as:

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad (15)$$

where,
F_c = Centrifugal Force (N)
m = Mass required (kg)
ω = Angular velocity (rad/sec^2)
v = Linear velocity (rad/sec)
r = Radius of rotation (m)
P = Required power (watt)
D_1 = Diameter of the driver pulley (m)
D_2 = Diameter of the driven pulley (m)
N_1 = speed of the driver (rpm)
N_2 = Reduced speed (rpm)

2.5 Performance Test Evaluation

Performance test evaluation was carried out at the completion of the developed modular bitter leaf washing and juice extraction machine. The tests were carried out at the designed operation speed reduction of 480 rpm. The tests were carried out so as to determine the following;

i. bitter leaf washing time using manual by mortar and pestle as reported in experimental design section and mechanical method using the developed machine.
ii. machine throughput capacity
iii. bitter leaf juice yield
iv. bitter leaf washing and juice extraction efficiency
The machine throughput capacity of the fabricated prototype machine was evaluated using Equation (16).

$$MTC = \frac{M_1}{T} \tag{16}$$

The bitter leaf extraction efficiency is given by Equation (17).

$$BE_{Eff.} = \frac{T1}{T_2} \times 100 \tag{17}$$

where,

MTC = Machine throughput capacity (kg/sec)
M_1 = Mass of bitter leaf (kg)
T = Bitter leaf washing and extraction time (sec.)
$BE_{Eff.}$ = Bitter leaf washing and extraction efficiency (%)
T_1 = Machine washing time (sec.)
T_2 = Manual washing time (sec.)

3. Results and Discussion

The developed machine is an electrical three-phase (0.75 hp) motor powered bitter leaf washing and juice extractor that masticates diced bitter leaves fed into it and at the same time squeezes out the juice. It uses stainless steel made beater to compact and crush the leaves against the cylindrical hopper incorporated with a perforated plate that allow juice to flow through while pulp is expelled through a separate outlet. The juice extractor is designed to work on the principle of oscillatory motion, crushing and squeezing, and is made up of six major units which include: main frame, feed hoppers, crushing unit, juice extraction unit, collecting unit and power transmission unit. The machine frame is trapezoidal in shape measuring with longer length 480 mm, shorter length 405 mm and height 550 mm. It consists mainly of hopper, electric motor, shaft, bearing, back and top cover, drain pipe and valve, circuit and switch board, rotary beater and V-belt attach to the pulley that rotate the shaft. The beaters are housed in the cylindrical hopper at a clearance of 2 mm. In operation, bitter leaves are introduced in the machine through the feed hopper. The machine crushes and presses the bitter leaves inside the cylindrical hopper with the aid of the beaters until juice is pressed out. The juice extracted is drained through the perforation provided at the bottom of the cylindrical barrel with the help of the drain pipe and valve. The motion of the rotating beater is achieved using shaft which is connected to an electric motor by the means of V-belt and pulley. The motion of the driver and driven pulley is such that it converts and transmits the rotating motion of the motor to reciprocating motion of the beater. The bitter leaf washing and juice extraction machine was evaluated to determine the power, speed, force, etc., that are required to wash and extract the juice. The speed reduction, angular velocity, centrifugal force, torque, and power required for the operation of the developed machine were obtained as 0.0127 m^3, 480 rpm, 50.285 rad/sec, 303.430 N, 3.03 Nm, 0.75 hp.

Fig. 8 shows the comparative analysis of manual washing time of bitter leaf and when machine is used. From the graph, a minimum washing time is required by the machine for processing of the same mass of bitter leaf when compared to the washing time of manual method via washing with the use of mortar and pestle.

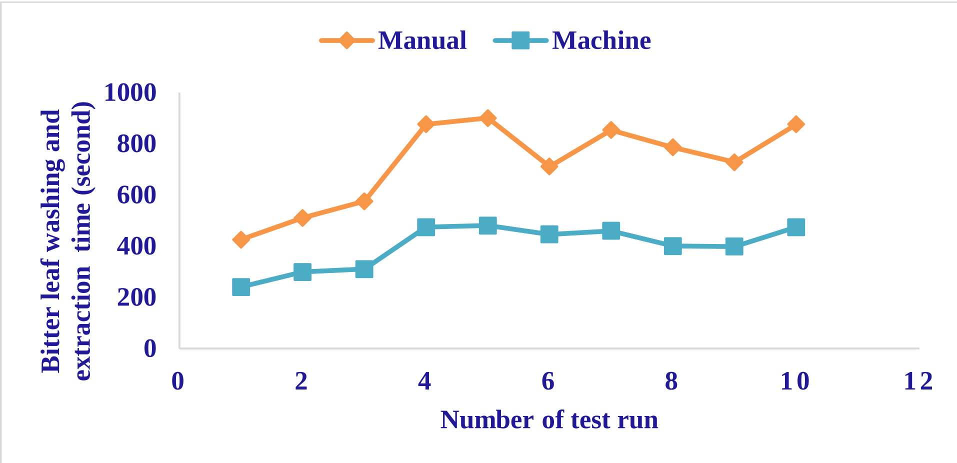
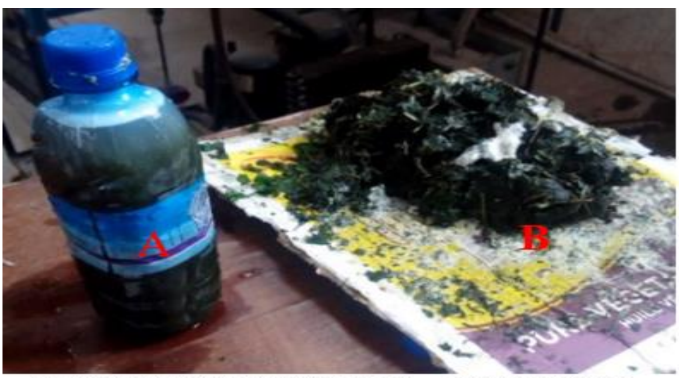


Fig. 8 Comparative analysis of washing and extraction time of bitter leaf using manual and machine

The juice extracted was filtered through the juice sieve into juice collector while the bitter leaf pulp is discharged through the outlet as shown in Fig. 9. It was observed that an average bitter leaf juice of 3.63 litre was extracted by machine against 3.60 litre extracted manually from average mass (0.4075 kg) of bitter leaves. Also, there was a tendency of better extraction by machine against manual extraction (Fig. 10).



*A. Sample of extracted butter leaf juice *B. Bitter leaf pulp

Fig. 9 Extracted bitter leaf juice and pulp

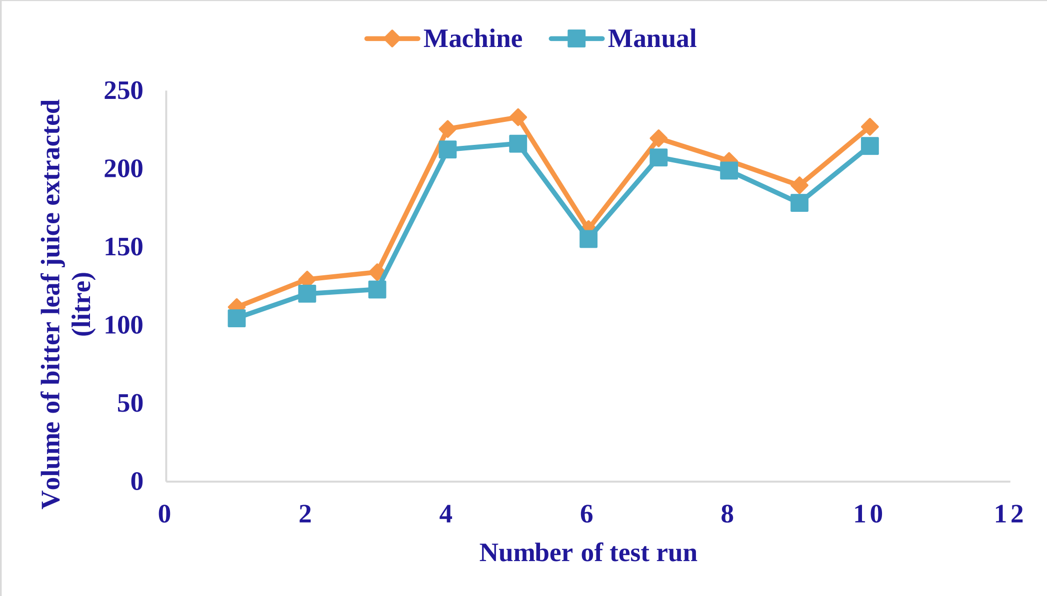


Fig. 10 Comparative analysis of volume of bitter leaf juice extracted using manual and machine

The bitter leaf washing efficiency of the machine and the machine throughput capacity were obtained as 55.00 % and 0.001023 kg/sec respectively. This simply implies that the developed machine is 55.00 % efficient than manual method of washing bitter leaf. More so, unlike the research work of [24] that made use of alcohol as a catalyst for the extraction of bitter leaf juice and in the process the alcohol was not recoverable at the end of the washing process. In this present research work, the juice and pulp extracted can be used for pharmaceutical purpose and also for direct consumption. Similarly, unlike the research work of [23] that juice extracted is relatively small and the macerated leaves are not recoverable. In this present work, there is effective washing chamber unit, storage unit, and there is provision to drain the extracted juice, thus, sufficient bitter leaf juice and pulp are extracted.

4. Conclusion

This research work has successfully presented a functional and highly efficient bitter leaf washing, and juice extracting machine by minimizing local technique of crushing and extracting bitter leaf juice, hence improving the hygienic and health condition of individuals and maintain fluid balance in the body. It was observed that the speed reduction, angular velocity, centrifugal force, torque, and power of 0.0127 m^3, 480 rpm, 50.285 rad/sec, 303.430 N, 3.03 Nm, 0.75 hp are required for sucessful operation of the machine. Also, a minimum average bitter leaf washing juice time of 398.28 seconds was required by the machine against manual extraction time of 724.13 seconds. The operational and process performance showed that the machine-washing method of bitter leaf is 55.00 % efficient than manual method of washing bitter leaf. Thus, with the bitter leaf washing and juice extraction machine, energy in washing bitter leaf manually is save and most importantly extracted bitter leaf juice is free from dirt unlike manual method which can be contaminator during extraction processes and time consuming.

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