International Journal of
Life Sciences
International Peer Reviewed Open Access Refereed Journal

Int. J. of Life Sciences, 2025; 13 (1): 1-7
ISSN:2320-7817(p) | 2320-964X(o)

Research Article Open Access

Development and Evaluation of a Multipurpose Fruit Pulping Machine

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Manuscript details:
Received: 18.10.2024
Accepted: 06.01.2025
Published: 12.01.2025

Cite this article as:
Lyaruu Honest M, Benjamin Yuda L and Makange Nelson R (2025) Development and Evaluation of a Multipurpose Fruit Pulping Machine, *Int. J. of Life Sciences*, 13 (1): 1-7.

Available online on http://www.ijlsci.in
ISSN: 2320-964X (Online)
ISSN: 2320-7817 (Print)

ABSTRACT

A multipurpose fruit pulping machine was designed, constructed and evaluated for performance using oranges, watermelon, pineapple, and tangerine. The machine was fabricated using locally available construction materials. The essential components of the machine include a feeding hopper, top cover, worm shaft, juice sieve, juice collector, waste outlet, transmission belt, main frame, pulleys and bearings. In operation, the worm shaft conveys, crushes, presses and squeezes the fruit to extract the juice. The juice extracted is filtered through the juice sieve into the juice collector while the residual waste is discharged through the waste outlet. The design analysis of the components provided the data that were used in the sizing, fabrication and assembling of the machine. Performance tests were carried out using oranges, watermelon, pineapple, and tangerine that were introduced into the machine. The performance indicators considered were percentage juice yield, extraction efficiency and extraction loss. Results showed that pineapple was leading in juice extraction efficiency (91.2%, followed by watermelon (90.5%). Further, it was found that watermelon was leading in juice yield (85.1%) and the last was tangerine (69.1%). The results also demonstrated that watermelon (2.9%) was observed to have the highest juice extraction loss, and the orange (2.3%) was the least. Powered by a 3Hp single-phase electric motor, the machine has a capacity of 1.24M^3/h. The machine is simple to operate and maintain, therefore it is recommended for smallholder and local fruit juice processors.

Keywords: Extraction efficiency, extraction loss, fruit, juice yield, pulping machine

INTRODUCTION

Fruit juice is a ready and rich source of vitamins A, B, and C, fiber, and minerals like Calcium and Iron for human consumption due to its uses as medicine, food, and appetite (Aremu & Ogunlade, 2016). Hence it is used in complementing the diet that is lacking in staple food.

Fruit juice is originally produced as a result of surplus production of fruits, but it is obtained from processing specially grown species for that purpose. The significant rate of postharvest loss, ranging from 40 to 50%, of the horticulture sector, including tropical fruits in Tanzania (Ekka & Mjawa, 2020), has restricted their year-round availability. To address this issue, turning to fruit juice as an alternative to fresh fruit can help mitigate the impact of these limitations. Fruit juice is the extract or the extractable fluid content of cells or tissues obtained through mechanical squeezing or pressing out the natural liquid contained in ripe fruits without the use of heat or solvent (Rajauria & Tiwari, 2018). According to (Caswell, 2009; Priyadarshini & Priyadarshini, 2018), fruit juice is considered the next best option for fresh fruit. Currently in Tanzania, the most dominant fruit juice in the market is extracted from fruits such as oranges, mangoes, pineapples, and guava (Dube et al., 2018).

Fruits are difficult to keep for a considerable length of time. Thus, ripe fruits are utilized either as fresh fruit or processed into juice and special products (Thompson, 2008). Most fruits are perishable in their natural state after harvest; deterioration sets in almost immediately due to metabolic activities that continue even after harvest (Issa et al., 2021; van der Maden et al., 2021). The perishable nature makes it difficult to store and preserve fruits. Hence, there is a gradual loss of flavor and nutritional value; hence, it is highly essential to process and preserve fruits to guarantee a regular supply of fruits at affordable prices (Thompson et al., 2018). Therefore there is a need to develop equipment for the effective extraction of juice from fruits to reduce post-harvest wastage and thereby ensure all-season availability of juice at reasonable costs; this will reduce post-harvest losses and prolong the shelf life of the product.

Different researchers developed fruit pulping machines whereby (Dikson, 2015) designed a fruit pulp processing machine to harness Baobab and Parinari Curatellifolia fruit, (Rodriguez-Rafael et al., 2024) designed a pulping machine specialized in granadilla using a system of blades and separation by gravity. (Oyeleke & Olaniyan, 2007) performed experiments in the laboratory on a small-scale fruit juice extracting unit for different fruits to determine the juice yield of tangerine, watermelon, pineapple, and grapes. (Aviara et al., 2013) designed, constructed, and evaluated a multi-fruit juice extractor using orange, pineapple, and melon. The machine operated on the principle of shear and compressive squeezing force.

Tanzanian households and small-scale farmers commonly extract juice using two methods: squeezing fruit with a muslin cloth or using a juicer/blender. The muslin cloth method involves manually cleaning, cutting, and squeezing the fruit, while juice from a juicer is refrigerated to stay fresh. Both methods are labour-intensive, time-consuming, and limited by human capacity, reducing production efficiency. The manual process also risks contamination, particularly when done in open areas, potentially causing health issues. Additionally, significant juice content is often left in the fiber after extraction.

By considering the problems and deficiencies facing small-scale farmers on using one of the two methods explained earlier during the extraction of juice from a variety of fruits, this study aimed to come up with a solution by designing a machine that enhances the production capacity, production efficiency, earn more profit and reduce loss during extraction. This machine is called the fruit pulping machine.

MATERIAL AND METHODS

Design Analyses and Calculations

Factors considered in the design of the fruit pulping machine include flexibility, simplicity, availability, and choice of material of construction (stainless steel was used as a food contact surface), cost, ease of maintenance, and aesthetics. Other materials used are mild steel, which was used to make the machine frame to support the machine; Nylon, which was used as the brush for the maceration process; and also Rubber, which was used as the belt for transmitting power from an electrical motor to the main shaft rotating inside the machine.

The machine was designed and developed at the Tanzania Engineering and Manufacturing Design Organisation (TEMDO) in Arusha. The development took place between January and May 2024.

Pulley and Belt

For a V-belt to overcome slippage during power transmission, the maximum permissible ratio of diameter of the shaft pulley to that of the electrical motor is 4:1. Therefore, the speed of the worm shaft was determined from equation (1);

$$\frac{N1}{N2} = \frac{D2}{D1} \quad \text{……………………………………………………… (1)}$$

Where $N1$ is the rated speed of the motor in rpm, $N2$ is the speed of the worm shaft pulley in mm, $D1$ is the diameter of the motor pulley in mm and $D2$ is the diameter of the shaft pulley in mm. Given that $N1$= 1450 rpm, $D1$= 70 mm, and $D2$= 250 mm, hence $N2$= 400 rpm.

The centre-to-centre distance and length of the transmission belt were calculated using equations (2) and (3);

$$C = \frac{D1+D2}{2} + D1 \quad \text{…………………………………………… (2)}$$

$$L = \frac{\pi}{2}(D1 + D2) + 2C + \frac{(D1-D2)^2}{4C} \quad \text{…………………… (3)}$$

Where, C and L are the center-to-center distance and length of the belt, respectively in mm. From equation (2) C = 230 mm and L =1000 mm.

Main Shaft

The main shaft is rotated by receiving power from the motor through belt transmission, joining the pulleys, one from the motor and another attached to the main shaft. As it rotates, it also rotates the cutter blade and Nylon brush attached to it. The diameter of the main shaft was determined by the equation (4);

$$d^3 = \frac{16T}{0.27\pi\delta} \quad \text{…………………………………… (4)}$$

Where, d is the shaft diameter in m, T is the maximum torque in Nm, δ is the yield stress in N/m^2 and pie is a constant. Given that T = 80 Nm, δ =100 N/m^2, hence, d = 24.76. Therefore, a stainless steel rod of diameter 25 mm and length 1010 mm was used for the main shaft.

Machine Capacity

The capacity of the machine was calculated using the formula presented in equation (5);

$$Q = 60 \times \frac{\pi}{4}(D^2 - d^2)\ pN\varphi \quad \text{……………………… (5)}$$

Where Q is the theoretical machine capacity in m3/h, D is the screw diameter in m, d is the shaft diameter in m, p is the screw pitch in m, N is the shaft speed in rpm, and φ is the filling factor. Substituting D=0.042 m, d =0.025 m, p=0.064 m, N=400 rpm and φ=0.9, hence Q = 1.24 m^3/h.

Power Requirement

The power required to drive the machine was calculated using the formula presented in equation (6);

$$P = \frac{QL\rho gF}{3.6} \quad \text{…………………………………………… (6)}$$

Where, P is the power required to drive the machine in W, L is the shaft length in m, ρ is the average density of fruit in kg/m^3, g is the acceleration due to gravity in m/s^2 and F is the material falling factor. Substituting Q=1.24 m^3/h, L=1.01m, ρ=980kg/m^3, g=9.81m/s^2 and F=0.5 into equation (6), hence P =2.34kw. To give allowance to power used in driving the pulley and other losses, the rated power was 2.5kw. Thus, a 3 hp single-phase motor was selected to drive the machine.

Machine Description and Operation

The fruit pulper machine consists of a hopper, drum (consisting of bottom and top cover plate), mesh sieve, cutter blade, brush, main shaft, pulley, juice outlet, fibre outlet and frame.

It is powered by a 3hp electric motor; the hopper is directly above the drum and is made of stainless steel material. The rotating shaft is fitted with cutter blades and nylon brushes. The mesh sieve covers the rotating shaft and they are both situated inside the drum.

The rotating shaft is directly attached to the pulley and power is transmitted from a 3hp electric motor through belt transmission to drive the shaft. All the components were made of stainless-steel material except the frame which was made of mild steel (Fig. 1).

In operation, the matured fruits such as Oranges, Watermelons, Pineapple, and Tangerine are purchased or harvested from the farm and are first cleaned with fresh water and peeled, i.e., removing the outer cover or skin from the fruit, while other fruits like Mango, Guava, etc., are peeled and removing the stone to remain with pulp only.

After peeling and stone removal, the fruit pulp is reduced in size so that it can be fed easily through the hopper. After that, the pulp is fed stepwise, depending on the load handling capacity of the motor, through the hopper, where at the bottom, there is a cutter blade attached to the rotating shaft in which a mastication process takes place to obtain a crushed pulp.

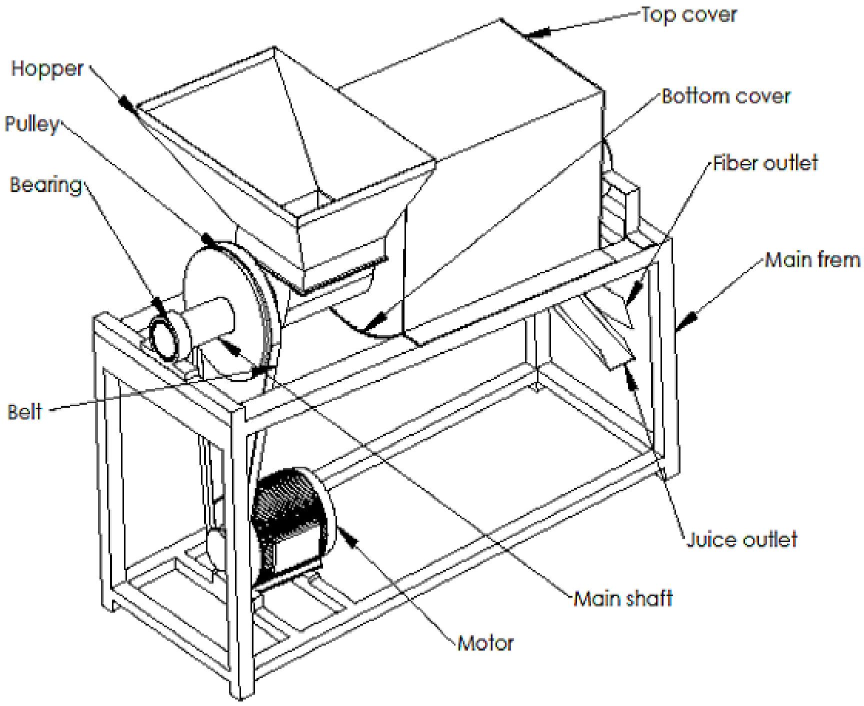

Figure 1: Fruit Pulping Machine

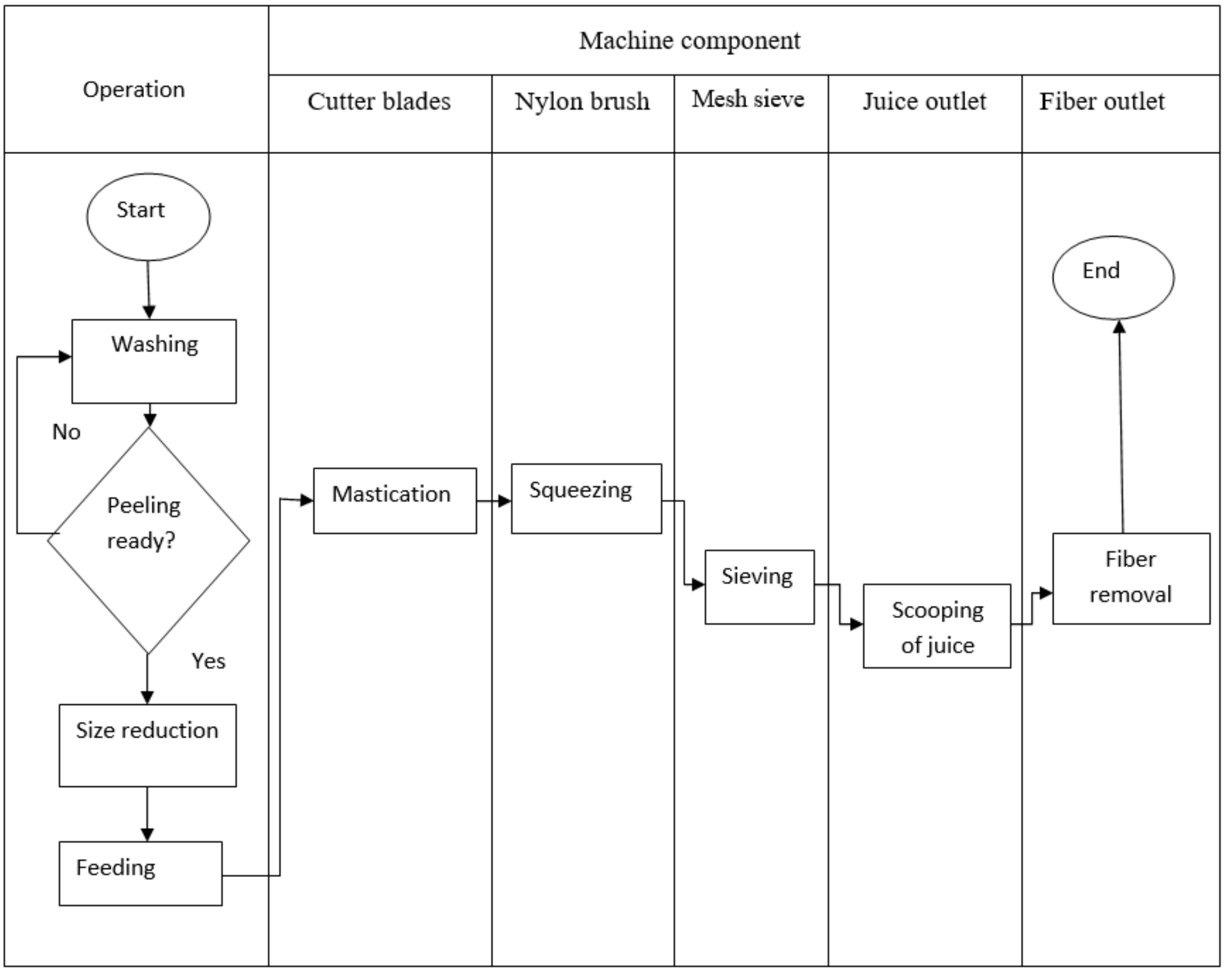

Figure 2: Machine Components and Operations

The crushed pulp is carried to the mesh sieve inside the drum by means of a spiral-shaped stainless steel plate also attached to the main shaft; the pulp is squeezed by a Nylon brush rotating together with the shaft to extract juice. Then, the straining process takes place within the mesh sieve, where the solid residual (fiber) is separated with juice through small openings around the mesh. Juice drips to the bottom cover of the drum passes through the juice outlet, and is collected in a small pan; lastly, the solid residual is removed through the fiber outlet.

Figure 2 presents the flow chart showing various machine components and operations from washing up to the delivery of juice.

Performance Evaluation of the Machine

Bulk quantities of oranges, pineapple, and watermelon were purchased from a market in Arusha City. The fruits were cleaned and sorted, and damaged ones were discarded. The machine performance test was carried out by pouring a known mass of fruit into the hopper. The power source was switched on to run the electric motor, which in turn powers the machine. The fruits in the hopper were then delivered into the extraction chamber and the machine was allowed to operate until the material was completely fed and extracted. After that, the mass of fruit fed into the machine, the mass of juice extracted, the mass of residual waste and the juice were recorded.

The mass of juice in chaff was determined using the method of ASAE (1983) as applied by (Aviara et al., 2013; Mushtaq, 2018). Each experiment was replicated three times for all types of crops.

The performance evaluation of the juice extractor was carried out based on the following indices used by (Tressler & Joslyn, 1961).

Juice Yield,

$$Jy = \frac{Q1}{Q1+Q2} * 100\% \quad (7)$$

Extraction Efficiency,

$$Ee = \frac{Q1}{XQ3} * 100\% \quad (8)$$

Extraction Loss,

$$JL = \frac{Q3-(Q1+Q2)}{Q3} * 100\% \quad (9)$$

Where; $Q1$ is the weight of the extracted juice, $Q2$ is the weight of residual products after extraction, X is the juice content before extraction, and $Q3$ is the weight of the fruit sample before extraction.

RESULTS

A small-scale juice extractor (Pulper machine) was designed, constructed and tested. The average juice yield, extraction efficiency and juice loss were 71.2, 78.7, 2.3 % for orange, 85.1, 90.5, 2.9 for watermelon, 74.3, 91.2, 2.4 for pineapple, and 69.1, 76.4, 2.5 for tangerine respectively (Table 1). These values are compared favorably with the findings of (Ishiwu & Oluka, 2004) and (Oyeleke & Olaniyan, 2007), indicating that the machine performed effectively.

The results of the percentage of juice yield, extraction efficiency, and extraction loss for oranges, watermelon, pineapple, and tangerine are presented in Table 1.

Figure 3: Juice Extraction Process

Table 1: Variation of percentage juice yield, extraction efficiency and extraction loss with type of fruit.

Performance Index	Type of fruit			
	Oranges	Watermelon	Pineapple	Tangerine
Juice yield	71.2	85.1	74.3	69.1
Extraction efficiency	78.7	90.5	91.2	76.4
Extraction loss	2.3	2.9	2.4	2.5

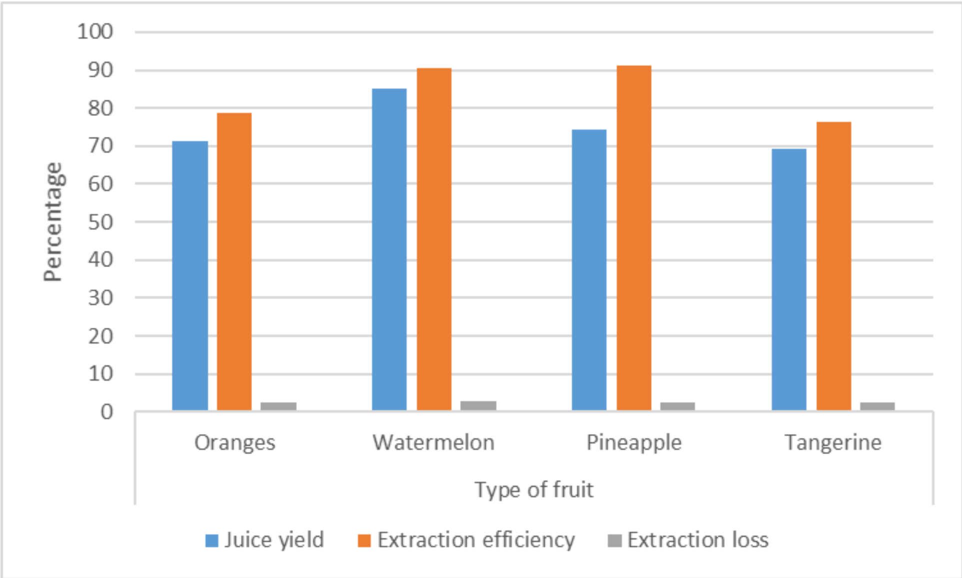

Figure 4: Performance of the Machine

It was found that pineapple (91.2%) is leading in juice extraction efficiency, followed by watermelon (90.5%). It was also found that watermelon led by juice yield (85.1%) and lastly tangerine (69.1). The extraction loss was highest for the watermelon (2.9%) and lowest for the orange (2.3%), as shown in Figure 4.

DISCUSSION

The results of this study highlight the varying efficiencies and yields of different fruits when processed using the newly designed low-cost juice-making machine. Notably, pineapple emerged as the most efficient fruit for juice extraction, achieving a remarkable 91.2% efficiency. This high efficiency can be attributed to the fruit's natural water content and fibrous structure, which likely facilitate better juice separation during processing.

In contrast, watermelon, despite having a slightly lower juice extraction efficiency of 90.5%, demonstrated the highest juice yield at 85.1%. This finding suggests that while the efficiency of extraction is critical, the overall yield is a more significant metric for small-scale entrepreneurs aiming to maximize their production output. The high juice yield of watermelon indicates its suitability for juice production, potentially making it a more profitable choice for small businesses.

Tangerine, with a juice extraction efficiency of 69.1%, lagged behind both pineapple and watermelon. The lower yield and efficiency may point to the challenges posed by the fruit's smaller size and thicker skin, which can complicate extraction processes. These results underline the importance of selecting the right fruit based on the specific processing capabilities of the machine and the desired end product.

Furthermore, the extraction loss percentages revealed that watermelon had the highest loss at 2.9%, while orange had the lowest at 2.3%. This variance suggests that the design of the machine may require optimization to minimize extraction losses across different fruit types. For small-scale entrepreneurs, even minor improvements in extraction efficiency could translate into significant cost savings and increased profit margins.

The machine can be used for small-scale fruit juice extraction in rural and urban communities. Further research needs to be done to improve the machine's capacity.

CONCLUSIONS

A multi-fruit pulping machine was designed, constructed and tested. The pulping machine was designed to extract juice based on the principle of squeezing fruits to obtain juice. Materials used for construction were locally available and cheap. Performance tests were carried out to investigate the extent to which the extractor can extract juice from selected tropical fruits. The machine was found to be efficient in extracting juice from oranges, watermelon, pineapple, and tangerine. The machine is recommended for small business entrepreneurs dealing with fruit juice.

Conflict of Interest: The authors declare no conflict of interest in relation to this research.

Acknowledgement
The authors are grateful to the general staff and administration of Tanzania Engineering and Manufacturing Design Organization (TEMDO), the Department of Industrial Development, the Ministry of Industry and Trade, and the School of Engineering and Technology, Sokoine University of Agriculture for the support in carrying out this work.

Data Availability Statement: Not applicable.

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Peer review information
IJLSCI thanks the anonymous reviewers for their contribution to the peer review of this work. A peer review file is available.

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