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Research Article

Multipurpose Fruit Juice Machine for Preventing Fruit Wastage in Nigeria Villages

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ABSTRACT

Fruits are produced in large quantities in developing countries because of the favourable climatic conditions but the level of spoilage is high. It is essential to extract and preserve fruit juice to have a regular supply throughout the year. Therefore, it was necessary to develop a machine that could be used to extract juice from several fruits. Thus, the objective of the research work was to develop a multipurpose small scale fruit juice machine that could be adopted by an average farmer in the rural regions to increase their juice intake. A fruit juice extractor was designed, developed and tested. The machine utilised a serrated auger for crushing the fruits before squeezing out the juice. The performance evaluation showed that the machine has an extraction capacity of 88.4 kg h^{-1} and 84.5 kg h^{-1} for pineapple and sweet orange respectively. The efficiencies of the juice extractor for pineapple and sweet orange were 91.13% and 85.96% respectively. The average production cost of the machine was estimated as 390 US dollars.

RESEARCH ARTICLE

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- Extraction capacity,
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INTRODUCTION

The demand for agricultural produce was forecast to increase by about 40% between 2012 and 2050 and that it would exert more pressure on the global natural resources (FAO, 2019). Food production, "from an environmental perspective, is resource-intensive" and its wastage could negatively impact the environment (FAO, 2019). Globally, about 14% of the food produced is lost after harvesting (FAO, 2019). For farmers in low-income countries such as Nigeria, minimizing on-farm losses could allow them to improve their food availability, supply, and incomes. Furthermore, an additional reduction in food losses could be experienced with food processing, leading to higher food supply and security. Fruit processing, an arm of the food processing industry, involves the conversion of fruits into pulp and juice that could be preserved for consumption year-round (El-ramady *et al.,* 2015).

Even though the environment and climatic condition of the tropical region favour the production of fruits in large quantities, fruits are found to be scarce during off-seasons because of the wastage incurred due to inadequate storage and processing facilities. Fruits are one of the highly perishable agricultural products that require negligible processing steps to fulfill effective inactivation of pathogens (Ojha *et al.,* 2021). Fruit juices are popularly perceived to be natural and that for them to retain the nutritional, colour, taste, composition and organoleptic features of the initial fruits, it is expected that the fruits are suitably processed without containing preservatives, sugar, artificial flavours and other ingredients (Cendres *et al.,* 2011; Rajauria and Tiwali, 2018).

Fruit juice extraction involves crushing, squeezing, and pressing fruits to produce juice and pulp. It could also be described as a process of physically changing the nature of the fruits to liquid and pulp. A few decades ago, manual extraction of juice from the fruit was the most common method in use which could be very slow and tedious. However, with the introduction of various techniques of extracting juice, the limitations and problems of manual fruit extraction have been reduced or eliminated. With the advent of fruit juice extractors, fruit processors have been able to save time, improved their efficiency and produce a large quantity of juice at a particular period with ease. Various mechanical fruit juicers had been developed and well-reviewed (Mushtaq, 2018; Nnamdi *et al.*, 2020). In Nigeria, various fruit juicing machines had recently been developed. These varied from manually operated fruit juice machines (Eyeowa *et al.*, 2017) to mechanically operated fruit juicing machines (Adejumo *et al.,* 2014; Aviara *et al.*, 2013; Omoregie *et al.*, 2018; Suleiman *et al.*, 2020). Though the machines were reported to be very cheap, they could be time-consuming (manually operated machine) and also result in crushing the seeds during processing which could affect the sensory and quality of the fruit juice (Mphahlele *et al.*, 2018).

Over the year, the production rate of fruits has increased in some regions of the tropical humid climate at some months of the year and become scarce during the remaining months of the year due to lack of storage facilities and processing techniques in the villages in Nigeria. Most of the small-scale machines that were developed were inaccessible for most of the villagers. In addition, if the machines were available, they were time-consuming and could also crush the seeds in the fruit during processing. Therefore, developing a time-saving and highly efficient multipurpose fruit juicing machine that could carefully extract juice from the fruits without affecting the quality of the juice would improve the standard of living of the villagers in Nigeria and at the same time reduce food wastage and losses.

The specific objectives of this study were; (1) to design and fabricate a multipurpose fruit juice machine capable of extracting juice without affecting its quality and (2) to test and evaluate the performance of the machine.

MATERIALS and METHODS

Machine design and description

The fruit juice extractor was designed on a PC (Figure 1a) using computer-aided design and engineering software (i.e., SolidWorks) and constructed at the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria. The machine was designed and developed to extract juice from various tropical fruits. The fruit juice extractor comprised the feeding (hopper), crushing and extracting units. The extraction unit comprised a screen for sieving the juice before discharging it from the machine. The prismatic hopper, made of stainless steel and the sides slanted at an angle 60º to the horizontal, was constructed on a removable concave top cover that protected the serrated auger. The shaft (serrated auger) with a diameter of 0.18 m, made of stainless steel and operated at an average speed of 1400 rpm, cut and squeezed the fruits fed into the hopper to produce juice and pulp. The juices from the fruits were collected through the juice delivery chute under the crushing unit while the effluent was collected at the pulp delivery chute at one of the ends of the juice extractor. The power was transmitted from the electric motor to the crushing unit through the driving and driven pulleys (Figure 1b). The juice extractor was constructed with less expensive materials in which the engineering qualities and cost were considered. The total cost of production of the machine was estimated as three hundred and ninety dollars ($ 390.00).

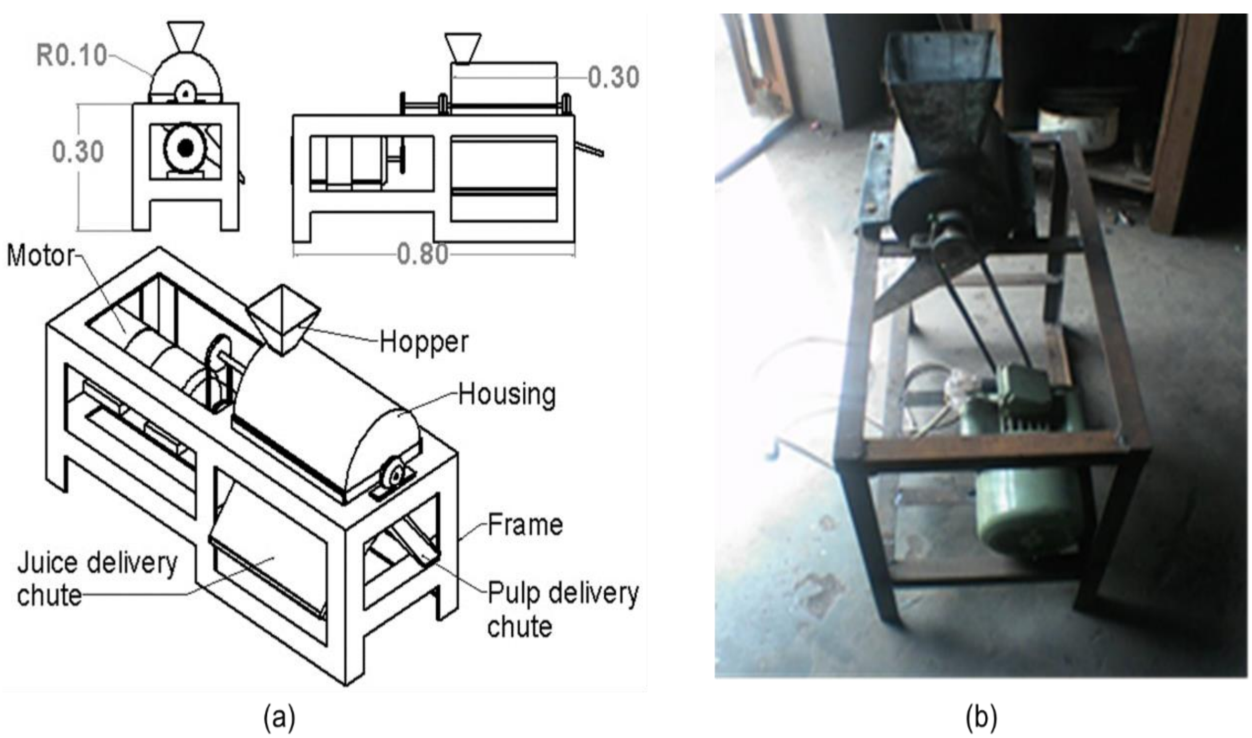

Figure 1. (a) Schematic and (b) pictorial view of the fruit juice machine (All dimensions in meters).

Shaft design

A shaft of a total length of 0.41 m has a uniformly distributed serrated auger of the length of 0.27 m. The machine has a strong frame that could absorb any possible stress and load. To determine the shear force and a bending moment of the shaft (beam) of the juicing machine, the weights of the shaft's component were mathematically determined. The weight of the pulley, made of mild steel, was estimated at 5.0 N. The weight of the serrated auger per unit length was estimated as 86.59 N m^{-1} and the machine was expected to be loaded with fruits of an average weight per unit length of 181.67 N m^{-1}.

The power required by the shaft

The linear velocity (V) of the shaft was estimated as 13.29 m s^{-1} using

$$V = rw \tag{1}$$

where r is the radius of the pulley and w is the angular velocity (revolution per second) of the pulley. The maximum bending moment (M_b) was estimated as 4.43 N m^{-1} using bending moment diagram (BMD) and the torsional moment (M_t) of 27.39 Nm was estimated using

$$M_t = \frac{P}{2\pi n} \tag{2}$$

Where; P is the estimated power required (4.044 kW or 5.4 HP) and n is the number of revolutions of the shaft per second. The diameter (d) of the shaft was estimated as 21.6 mm using

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{3}$$

where S_s is the allowable stress (34.6 MPa), K_b is the bending stress factor (1.5), K_t is the torsional stress factor (1.0), M_b is the maximum bending moment, and M_t is the torsional moment. The factor of safety considered suitable for the shaft diameter was 1.35. In this work, a standard shaft diameter of 25 mm was selected for the machine since a 21.6 mm diameter shaft was not readily available for the work.

Design of auger

The auger on the shaft (Figure 2) was designed to convey the pulps of the fruit to the pulp delivery chute. For the auger design, the theoretical capacity of the auger, which would convey materials of an average mass of materials of 5.0 kg, was estimated as 0.0222 m^3 min^{-1} using

$$Q = \frac{(D^2 - d^2) \times P_a \times n \times \emptyset}{36.6} \tag{4}$$

Where D is the pitch diameter of the auger (m), d is the diameter of the shaft (m), P_a is the pitch of the auger, n is the shaft speed (revolution per minute), $\emptyset$ is the filling factor (0.45). The torque T_c of the auger was estimated as 2.80 N m-1 using

$$T_c = \frac{975 \times P}{n} \tag{5}$$

Where; P and n are the power required and the speed of the auger respectively. The load propulsion speed V_c and load per unit length V_c of the auger of 0.94 m s-1 and 6.56×10^{-3} N m-1 were estimated using

$$V_c = \frac{P_a \times n}{60} \tag{6}$$

and

$$L_c = \frac{Q}{3.6V} \tag{7}$$

respectively. The axial thrust *(Th)* of the auger of 7.08×10^{-4} N was estimated using

$$Th = L_c \times L \times \mu \tag{8}$$

Where; L is the length of the auger and μ is the friction coefficient (0.4).

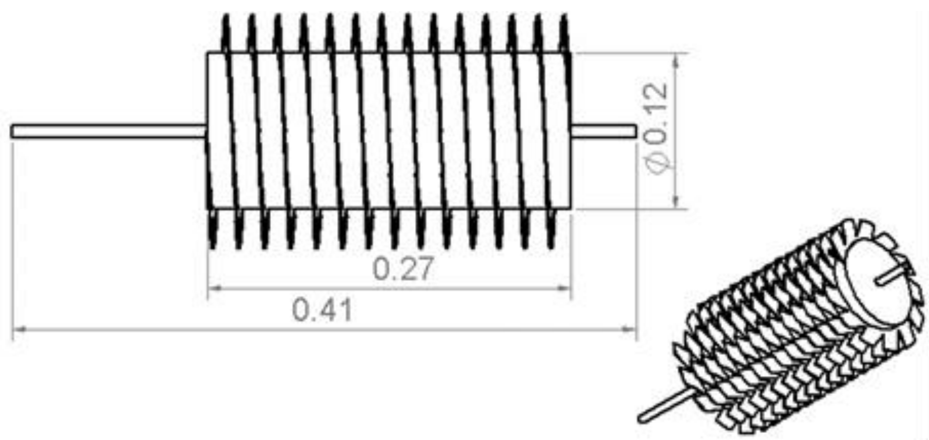

Figure 2. The serrated auger (all measurements in metres).

Belt and pulley design

The choice of the belt for the machine, over other power transmission devices such as chain, was based on its ability to prevent vibration transmission, less expensive, ability to transmit power between the axes of widely spaced shafts, and that its damage during operation would not negatively affect the machine. Therefore, the design details of the belt (Figure 3) of the machine are as follows. The wrap angle β of the belt was estimated as 180° using

$$\beta = 180° + 2sin^{-1}\frac{(R_1 - R_2)}{C} \qquad (9)$$

Where; R_1 and R_2 are the radius of two pulleys (note that the pulleys have the same diameter), C is the distance between the centers of two pulleys. The length of the belt was estimated as 0.90 m using

$$L_b = 2C + \frac{\pi}{2}(D_1 + D_2) \qquad (10)$$

Where; D_1 and D_2 are the diameters of the two pulleys. The tensions (T_1 and T_2) on the belt were estimated at 76.8 N and 24.97 N using

$$T_1 = Allowable\ stress\ (0.06\ MPa) \times Thichness\ of\ belt\ (0.02m) \times width\ of\ belt \qquad (11)$$

and

$$\frac{T_1 - mV^2}{T_2 - mV^2} = e^{\mu\beta} \qquad (12)$$

where m is the mass of the belt (kg), V is the estimated belt's speed (m s^{-1}), μ (0.25) is the friction coefficient between the belt and the pulley. The power capacity (P_b) of the belt was estimated as 0.25 kW using

$$P_b = (T_1 - T_2)V. \qquad (13)$$

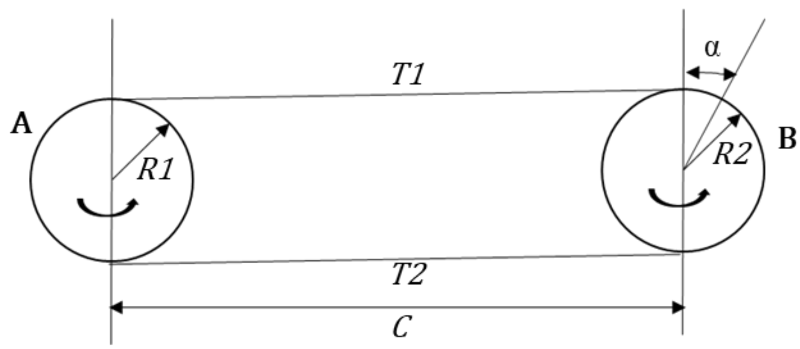

Figure 3. Belt design details

Experimental design and data analysis

The machine was tested with some fruits (sweet oranges and pineapple) based on their cultivation by most of the farmers. A total of 15 kg of each of the fruits was acquired from the local market during the study. The performance of the juice extractor was evaluated based on the machine speed (1400 rpm) and the two different types of fruits used (sweet oranges and pineapple). A motor with 1400 rpm was selected because of its price and availability in the local market. Most of the motors with variable speeds are expensive and farmers could find it difficult to replace if the need arises. The test was repeated three times with each containing 5 kg of the fruits. The time taken (minutes) by the machine to complete the extraction was noted. The extracted juice was collected and weighed as kg. The juice extraction capacity (kg h^{-1}) and the juice extraction efficiency (%) of the machine were determined using appropriate expressions.

$$\text{Juice extraction capacity (kg } hr^{-1}) = \frac{\text{mass of juice extracted}}{\text{Time spent for the extraction}} \tag{14}$$

$$\text{Juice extraction efficiency (\%)} = \frac{\text{mass of juice extracted}}{\text{mass of maximum extractable juice}} \times 100 \tag{15}$$

The data were processed using Microsoft Excel 2019 and analysed using JMP® Pro 13.0.0 (SAS Institute Inc., 2016). The data was subjected to statistical analysis (t-test) to determine the performance of the machine at a statistical significance of 5%.

RESULTS and DISCUSSION

The performance of the fruit juice machine was evaluated based on its extraction capacity and extraction efficiency. As shown in Figure 4, it could be observed that a higher mean extraction capacity per unit time (88.4 kg h^{-1}) of the machine was obtained from the pineapples. Since the fruits were ripe and peeled before being loaded into the machine, it could indicate that the machine was able to crutch and extract almost all the juice in the pineapple than it could with the sweet orange (84.50 kg h^{-1}). Eyeowa *et al.* (2017), reported that a manual juice extractor has an average extraction capacity of about 53% for both pineapple and orange while about 1.0 kg of the total orange (3.80 kg) loaded into a fruit juicing machine developed by Omoregie *et al.* (2018) was reported not be properly processed. Similarly, Aviara *et al.* (2013) reported that a multipurpose fruit juicer could produce about 79% and 77% of juice from the peeled pineapple and orange loaded into it respectively. The t-test analysis carried out showed that there was a significant difference ($p = 0.0047$) between the mean extraction capacity of the machine when tested with pineapple and sweet orange.

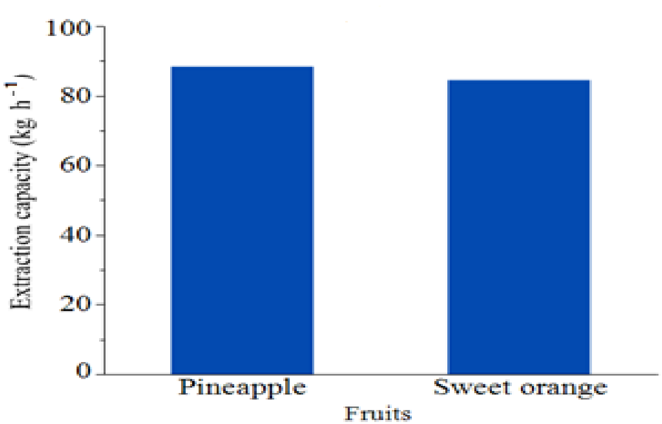

Figure 4. Juice extraction capacity of the fruit juicing machine.

The extraction efficiency of the fruit juice machine, as shown in Figure 5, indicated that the efficiency of the machine, when tested with pineapple (91.13%), was higher than that of sweet orange (85.96%). Higher efficiencies were reported by Aviara *et al.* (2013) who indicated that their multipurpose juice extractor achieved 97% and 94% extraction efficiencies when tested with peeled pineapple and orange respectively. However, the findings of Eyeowa *et al.* (2017) showed that the efficiency of a manually operated juicing machine when tested with orange (about 66%) was higher than that of pineapple (about 64%). The result of the statistical analysis (t-test) conducted showed that there was a significant difference ($p < 0.0001$) between the mean extraction efficiencies of the fruit juice machine when tested with pineapple and sweet orange.

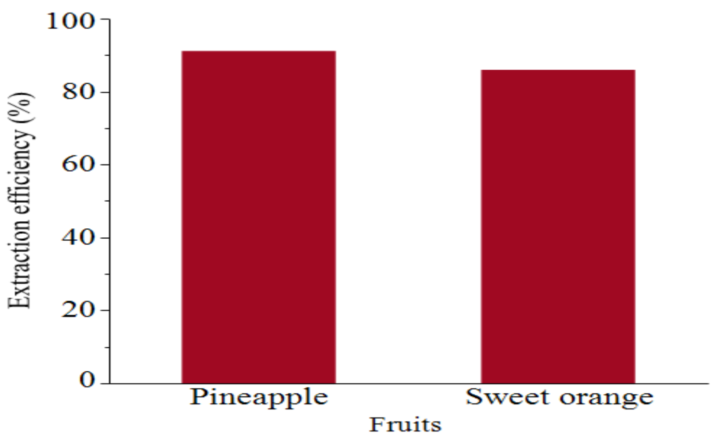

Figure 5. Juice extraction efficiency of the fruit juicing machine.

CONCLUSION

A multipurpose juicing machine with a serrated auger was developed and tested with peeled pineapples and sweet oranges. The results of this study have shown that replacing the smooth edge screw auger in the juicing machine with a serrated auger could increase the extraction capacity (kg h^{-1}) and efficiency (%) of the fruit juice machine. It has also been found out that using a serrated auger could increase the extraction of juice from pineapple which had been reported "to possess valuable bioactive compounds for medical purposes, increase appetite for food nourishment" and many other benefits (Mohd Ali *et al.*, 2020).

DECLARATION OF COMPETING INTEREST

The author would like to declare that there is no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author would like to declare that he solely developed all the sections in this manuscript.

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