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ORIGINAL ARTICLE

Development of a small scale orange juice extractor

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Abstract A small scale motorized orange juice extractor was designed and fabricated, using locally-available construction materials. The essential components of the machine include 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 juice collector while the residual waste is discharged through waste outlet. Result showed that the average juice yield and juice extraction efficiency were 41.6 and 57.4%, respectively. Powered by a 2 hp electric motor, the machine has a capacity of 14 kg/h. With a machine cost of about $100, it is affordable for small-scale citrus farmers in the rural communities.

Keywords Orange fruits · *Citrus sinensis* · Juice extractor · Design · Construction · Testing · Juice yield · Extraction efficiency · Machine cost

Introduction

Citrus is a large family and include orange (*Citrus sinensis*), tangerine (*Citrus x tangerina*), grapefruit (Citrus paradisi), lemon *(Citrus limon)* and lime *(Citrus aurantifolia)*. These fruits are highly perishable after harvest and are susceptible to spoilage by mechanical, chemical and environmental effects, and thus necessitating processing into juice. The juice, which can be consumed freshly or processed further into healthful beverages, are good sources of potassium, vitamins B and C, folic acid and other nutrients.

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There are two principal methods of juice extraction from fruits. In the first method, the fruits are crushed and pressed continuously in a single operation. In the second method, fruits are sliced into smaller pieces and then processed by a suitable pressing machine to extract the juice. The common types of juice extraction machines include: simple juicers, manual juicers and continuous juicers. Automatic juicers are sub-divided into centrifugal juicers and masticating juicers.

Badmus and Adeyemi (2004) designed and fabricated a small scale whole pineapple fruit juice extractor. The machine consists of beater blades and a shaft in conjunction with a powered screw pressing mechanism. The machine successfully processed 12 kg of ripe pineapple fruit into 8 L of pineapple juice. Ishiwu and Oluka (2004) developed and carried out performance evaluation of a juice extractor as a function of its extraction efficiency. The extractor consisted of screw jack, frame, connecting screw rod, pressing mechanism, interlock, feeding pot, receiving pot and discharge mechanism. Performance tests revealed a juice yield, extraction efficiency and extraction loss of 76, 83 and 3%, respectively.

Kailappan et al. (2005) fabricated and evaluated a tomato seed extractor having a capacity of 180 kg of fruits/h. With a unit cost of $190, the extractor had a seed extraction efficiency of 98.8%. Compared with manual seed extraction method, the extractor had a saving in time and saving in cost of 96.6 and 89.6%, respectively. As a means of preservation and value addition to guava, Nidhi and Matthew (2006) developed guava candies by modifying the normal procedure for preparing confectionary items. Report showed that the candies prepared can be safely stored for 2 and 4 months under ambient and refrigerated conditions, respectively.

Orange plant is grown and cultivated in most parts of Nigeria. The fruit is abundant in the production season and always very scarce and expensive during the off season. Attempts to store fruit in its fresh and natural form have failed due to lack of effective storage and preservation methods. Processing this fruit into juice is a better way of storage, preservation and value addition. Therefore, the objective of this work was to design, construct and test a small scale machine for extracting orange juice for rural communities.

Description of the extractor

The main components of the machine include hopper, top cover, worm shaft, juice sieve, juice channel, waste outlet and main frame. In operation, the machine conveys, crushes and presses with the aid of worm shaft until the juice is squeezed out of fruit into juice channel through the juice sieve. The residual waste is discharged through waste outlet. The machine is powered by a 2 hp single-phase electric motor.

Design considerations

While designing the machine, considerations included: high processing capacity and efficiency, quality of juice, quality, availability and cost of construction materials. Other considerations included the desire to make the main components with stainless steel to ensure safety and quality of juice; to design the pressing chamber to accommodate the required quantity of raw materials (orange fruit) and the worm shaft to ensure maximum conveyance, crushing and pressing of raw materials. Also considered was a strong main frame to ensure structural stability and strong support for the machine.

Design computations

Pulley and belt: For a V–belt to overcome slippage during power transmission, the maximum permissible ratio of diameter of shaft pulley to that of electric motor is 4:1. Therefore, the speed of worm shaft was determined from the following equation as:

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{1}$$

where, N_1 is the rated speed of the motor in rpm, N_2 is the speed of the worm shaft in rpm, D_1 is the diameter of the motor pulley in mm and D_2 the diameter of the shaft pulley in mm. Given that N_1 = 1450 rpm, D_1 = 90 mm and D_2 = 300 mm, hence N_2 = 435 rpm. The required speed of the worm shaft is 435 rpm.

The centre-to-centre distance and length of the transmission belt were calculated using Equations 2 and 3 below as:

$$C = \frac{D_1 - D_2}{2} - D_1 \tag{2}$$

$$L = \frac{\pi}{2}\left(D_1 + D_2\right) + 2C + \frac{\left(D_1 - D_2\right)^2}{4C} \tag{3}$$

where, C and L are the centre-to-centre distance and length of the belt, respectively in mm. With C = 285 mm (from Equation 2), D_1 = 90 mm, D_2 = 300 mm and π = 3.142, hence L = 1221 mm (from Equation 3). Therefore, a V-belt of specification A-45, 12.5 × 1220 mm was selected.

Worm shaft: The worm shaft is the conveying, crushing and pressing unit of the machine. The diameter of the shaft was determined from the equation given by Shigley and Mitchell (1983) as:

$$d^3 = \frac{16T}{0.27\pi\delta_o} \tag{4}$$

where, d is the shaft diameter in m, T is the maximum torque in Nm, δ_o is the yield stress in N/m^2 and π is a constant. Given that T = 60 Nm, δ_o = 200 N/m^2, π = 3.142, hence, d = 17.82 mm. Therefore, a stainless steel rod of diameter 20 mm and length 660 mm was used for the worm shaft.

Machine capacity: The theoretical capacity of the machine was calculated by the equation given by Onwualu et al. (2006) as:

$$Q = 60\, x \frac{\pi}{4}(D^2 - d^2)pN\varphi \tag{5}$$

Where, Q is the theoretical machine capacity in m^3/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 (rotational) speed in rpm and ø is the filling factor. Substituting D = 0.042 m, d = 0.020 m, p = 0.064 m, N = 435 rpm and ø = 0.9, hence, Q = 1.432 m^3/h.

Power requirement: The power required to drive the machine was calculated using an equation adapted from Onwualu et al. (2006) as:

$$P = \frac{QL\rho_d gF}{3.6} \tag{6}$$

where, P is the power required to drive the machine in W, L is the shaft length in m, ρ_d is the density of orange in kg/m^3, g is the acceleration due to gravity in m/s^2 and F is the material (falling) factor. Substituting Q = 1.432 m^3/h, = 0.66 m, ρ_d = 734 kg/m^3, g =9.81 m/s^2 and F = 0.5 into Equation 3.6, hence, = 0.945 W. To give allowance to power used in driving the pulley and other losses, the rated power was 1000 W. The power of the electric motor to drive the system was estimated as:

$$P_m = \frac{P}{\eta} \tag{7}$$

where, P_m is the power of electric motor in W and η is the efficiency of the motor in decimal. Given that = 0.8, therefore, P_m = 1,250 W or 1.676 hp. Therefore, a 2 hp single-phase electric motor was selected to drive the machine.

Construction process

Fabrication was carried out at the Central Engineering Workshop, University of Ilorin, Nigeria. Fig. 1 shows the engineering drawings of the juice extractor. The hopper was fabricated from a standard length of 1.5 mm thick stainless steel sheet. Two pieces of dimension 200 × 100 × 230 mm and 2 pieces of dimension 200 × 120 × 230 mm were cut from the stainless sheet. The worm shaft was fabricated from a stainless steel rod of diameter 25 mm and length 660 mm which was machined to 20 mm diameter on the lathe. A stainless steel square bar of dimension 10 × 10 × 850 mm was wound round the shaft spirally to form the screw at a decreasing pitch.

The pressing chamber (shaft housing) was fabricated from a stainless steel pipe of 2 mm thickness, 250 mm diameter and 600 mm long. The lower part of the pressing chamber was slotted by a power hacksaw to serve as the perforated base. The juice extracted flows through the perforated base and sieved by stainless mesh to the juice channel from where it is collected. The main frame and electric motor stand were fabricated from an angle iron of dimension 50 × 50 × 50 mm. Following the design specifications, the angle iron was cut into appropriate sizes and welded together to serve as the support for the machine and electric motor. The specification of construction materials is shown in Table 1.

Performance evaluation

Testing procedure: Fresh orange fruits were obtained from a horticultural garden in Ilorin. The fruits were washed, peeled and cut into slices. The machine was set into operation and 3 kg of the oranges were introduced through the feeding hopper. In the pressing chamber, the worm shaft conveyed, crushed and pressed the oranges to extract the juice. Both the juice extracted and the residual waste were collected and weighed separately. From the values obtained, juice yield, extraction efficiency and extraction loss were determined by using Tressler and Joslyn (1961) equation as:

$$J_Y = \frac{100\, W_{JE}}{W_{JE} + W_{RW}} \% \tag{8}$$

$$J_E = \frac{100\, W_{JE}}{x W_{FS}} \% \tag{9}$$

$$E_L = \frac{100\left[W_{FS} - (W_{JE} + W_{RW})\right]}{W_{FS}} \tag{10}$$

where, J_Y, J_E and E_L are juice yield, extraction efficiency and extraction loss, respectively in%; W_{JE}, W_{RW} and W_{FS} are weights of juice extracted, residual waste and feed sample respectively in g and x is the juice content of orange in decimal. Each test was carried out in triplicates.

Results and discussion

The average juice yield, extraction efficiency and juice loss were 41.9, 57.4 and 7.3%, respectively. These values compared favourably with the findings of Ishiwu and Oluka (2004) and Oyeleke and Olaniyan (2008) indicating that the machine performed effectively.

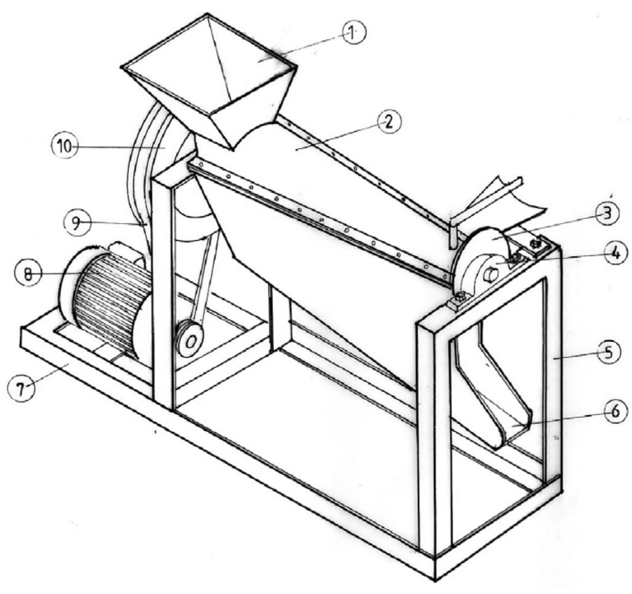

Fig. 1 Isometric view of orange juice extractor: 1 – Hopper; 2 – Extraction Chamber; 3 – Dic plate; 4 – Bearing; 5 – Main frame; 6 – Juice collector; 7 – Motor stand; 8 – Electric motor; 9 – Transmission belt; 10 – Pulley

Table 1 Materials used for construction of the orange juice extractor and their specifications

Materials	Specifications	Quantity
Stainless steel sheet	1.5 mm thickness, 1/4 standard size	1
Stainless steel rod	Φ 25 mm, standard length	1
Stainless steel square bar	10 × 10 mm, 1/2 standard length	1
Angle iron	50 × 50 mm, standard length	1
Stainless steel mesh	1 mm thickness, 1/4 standard size	1
Stainless steel sheet	1 mm thickness, 1/4 standard size	1
Cast iron ball bearing	Φ 20 mm	2
Welding electrode	Gauge 10 ordinary	½ pack
Welding electrode	Gauge 10 stainless	½ pack
Bolts and nuts	M12	36
Cast iron pulley	Φ 300 mm	1
Cast iron pulley	Φ 90 mm	1
V - belt	A 50, 12.5 × 1325 mm	1
V - belt	A 45, 12.5 × 1200 mm	1

Conclusion

A small scale orange juice extractor was designed, constructed and tested. The extractor was portable enough for local production, operation, repair and maintenance. Results of the tests revealed a juice yield of 41.5% with an extraction efficiency of 57.4%. Powered by a 2 hp single-phase electric motor, the machine has a capacity of 14 kg/h with a production cost of $100. This machine can be used for small scale orange juice extraction in the rural and urban communities. A cottage orange juice processing plant based on this technology can engage the services of two persons at the same time providing quality orange juice at lower cost.

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