Development and Performance Evaluation of a Manually-Operated Multipurpose Fruit Juice Extractor

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Abstract - A simply and manually-operated multipurpose fruit juice extractor was designed, constructed and its performance was evaluated in terms of juice yield, extraction efficiency, juice content, extraction loss and extraction capacity. The machine has two major parts which are: the extraction chamber and the structural frame. The extraction chamber is made of stainless steel and consists of a turning handle (ϕ24.5 x 400mm), screw rod (ϕ32 x 620 mm), compression plate (ϕ100 mm), perforated inner cylinder (ϕ115 x 180 mm), non-perforated outer cylinder (ϕ120 x 180 mm) and discharge pipe. The structural frame (350 mm x 415 mm x 60 mm) is made of mild steel of U-channel section. The machine basically works on the principle of transmission of compressive force to rupture the juice cells of the fruit for the liberation of juice. Sweet orange, watermelon, red apple, green apple, pineapple, lime, lemon and grape were used for the performance evaluation process. Results obtained showed that pineapple had the highest values of juice yield (68.74%),juice content (66.40%), extraction capacity (92.85 g/min) and extraction efficiency (82.99%) while sweet orange and lime had the lowest extraction loss and extraction capacity of 1.67% and 29.81 (g/min) respectively.

Keywords - Fruits, juice extraction, manually-operated, performance evaluation.

1. Introduction

Fruits remain one of the most consumed seasonal agricultural produce whose formation is mainly from developed ovary of seed plants. Various fruits such as orange, pineapple, pawpaw and mango are grown in Sub-Saharan parts of Africa. Fruits are good sources of nutrients such as vitamins and minerals (Aremu and Ogunlade, 2016). Fleshy parts of fruits contain high content of water, sugar and dietary fibre which are beneficial to human medicinally (Bates and Crandall, 2001) and have low calorific values (Oguntuyi, 2013). Fruit juice extraction is the process of squeezing the liquid content out of fruits to ease effective processing and storage thereby preventing unnecessary wastage. Some of the unit operations involved in fruit juice extraction are: sorting, grading, rinsing, peeling, cutting, juice formulation, clarification, storage and packaging (Abulude et al, 2007). Extraction can be done manually or mechanically. Recently, different types of juicers have been effectively used for extraction purpose. The common ones are the manual juicers, simple juicers and automatic juicers (masticating juicers and continuous juicers) (Olaniyan, 2010).

Ogunsina and Lucas (2008) developed a manually operated cashew juice extractor operating on screw press principle. Results from performance evaluation indicated that juice output was 1.02 litres/hr and the average juice extraction efficiency was 85.38%. Also, Oguntuyi (2013) developed and fabricated a manual fruit juice extracting machine with a capacity of 8.45litre/hour at an applied force of 0.28 kN. The performance evaluation of the machine revealed that the extraction efficiency of the machine was about 90%.

Abulude et al. (2007) designed and evaluated a manually operated juice extractor. The machine was tested with orange and pineapple; and results showed that the machine produced efficiencies of 83.86 and 85.38% with extraction capacities of 1.29 kg/hr and 1.23 kg/hr for orange and pineapple respectively. Furthermore, Aremu and Ogunlade (2016) developed and evaluated a portable multipurpose fruit juice extractor. The performance evaluation of the machine was carried out using peeled and unpeeled samples of watermelon, pineapple and orange fruits. It was reported that the juice yield, extraction efficiencies, extraction losses for peeled and unpeeled orange were 45.0 and 45.8%; 50.8 and 58.4%; 9.6 and 3.0% respectively while 51.2 and 47.6%; 66.7 and 50.8%; 5.6 and 3.1% were obtained using peeled and unpeeled pineapple fruits respectively.

Moreover, the juice yields, extraction efficiencies, extraction losses of peeled and unpeeled water melon were 31.8 and 46.3%; 37.9 and 52.2%; 6.7 and 0.9% respectively. Also, a manual juice extractor was designed, constructed and evaluated by Sylvester and Abugh (2012). The extraction efficiency and extraction capacity of the machine were: (83.86%, 1.29 kg/h) and (85.38%, 1.23kg/h) for orange and pineapple juice respectively. Wastage of fruits due to inadequate processing and storage facilities leads to scarcity in market, thus causing high purchase cost of available ones. Also, apart from epileptic power supply affecting the regular use of motorized fruit juice extractors, and high purchasing cost of foreign made machines; most available juice extractors are cumbersome and complex in their operation and maintenance. These conditions are not suitable or appropriate for local or small scale fruit juice processors. Therefore, the main objective of this research was to develop and evaluate the performance of a simply and manually-operated multipurpose fruit juice extractor.

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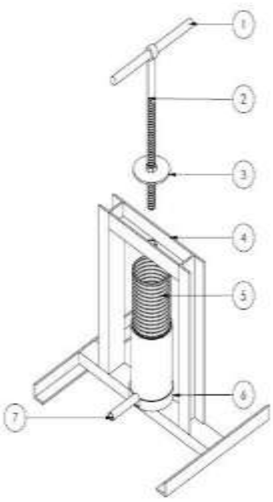
2 Materials and Methods

2.1 Description of the Machine

The machine consists of two major parts; these are the extraction chamber and the structural frame. The extraction chamber made of stainless steel consists of a turning handle (ϕ24.5 x 400mm), screw rod (ϕ32 x 620 mm), compression plate (ϕ100 mm), perforated inner cylinder (ϕ115 x 180 mm), non-perforated outer cylinder (ϕ120 x 180 mm), and discharge pipe. The structural frame (350 mm x 415 mm x 60 mm) is made of mild steel of U-channel section. Fig.1 and Fig. 2 are the part list, orthographic and isometric views of the machine.

2.2 Working Principle of the Machine

The machine basically works on the principle of transmission of compressive force. The loaded fruits inside the perforated internal cylinder of the compression chamber of the machine receive compressive force applied by the operator via the turning handle and the screw rod. Juice will be liberated from the fruit and collected through the discharge pipe when the juice cells that are naturally embedded in the fruits can no longer withstand the applied force.



PART NO.	PART NAME
1	TURNING ROD
2	PRESS SCREW
3	COMPRESSION PLATE
4	FRAME
5	PERFORATED INNER CYLINDER
6	EXTERNAL CYLINDER HOLDER
7	JUICE DISCHARGE PIPE

Fig 1: Part List of the Machine

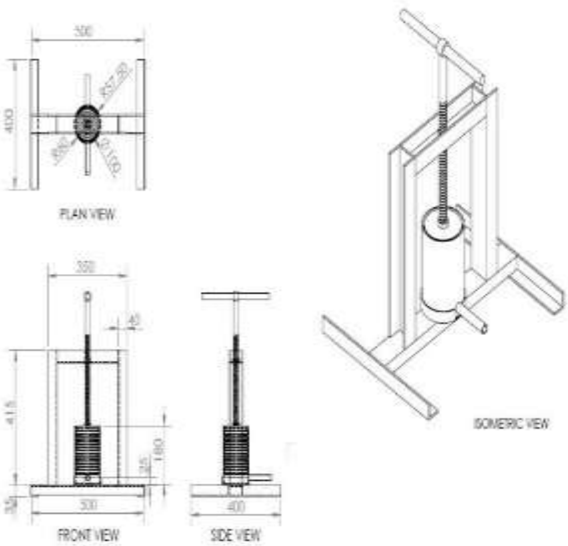


Fig.2: Orthographic and Isometric views of the machine

2.3 Design Calculations

2.3.1 Screw Rod (Shaft)

Shaft design especially for juice extractor involves analysis of strength and rigidity. For a solid shaft, torsional load could be obtained from ASME equation as reported by Hall et al. (1980). Equation (1) shows the formula for a given solid shaft as stated by Aremu and Ogunlade (2016)

$$T = Fx \qquad (1)$$

where, T is the turning moment (121.50 Nm), F is the force (675 N) (required by human) as suggested by Reinhold (1986) and$x$ is the distance at which the fruits will be compressed and extracted (0.18 m). Equation (2) was used to calculate the shaft diameter of the juice extractor

$$D^3 = \frac{16T}{S} \qquad (2)$$

where, S is the allowable stress (55MPa for shaft without keyway), D is the shaft diameter (32 mm) T is the Torque (121.50 Nm).

The rigidity of the shaft for operation was considered based on allowable angle of twist and for a circular shaft. Equations (3-5) shows the formula relating angle of twist and polar moment of inertia as stated by Aremu and Ogunlade (2016)

$$\emptyset = \frac{TL}{GJ} \qquad (3)$$

where, Ø is the angle of twist (3°), T is the Torque (121.50 Nm), L is the diameter of shaft permissible for torsional deflection (25 mm), G is the modulus of rigidity of shaft material (80 GN/m^2) and J is the polar moment of inertia for shaft section is given in Equation 4 as:

$$J = \frac{\pi D^4}{32} \qquad (4)$$

Substituting for D in equations

$$D^4 = \frac{32TL}{\pi G\emptyset} \qquad (5)$$

From the calculations, in order to allow stress and twist, a shaft of diameter 32 mm was used in the construction process. Equation (6) shows the formula for required pressure to compress and rupture fruits based on maximum applicable load

$$P = \frac{F}{A} \qquad (6)$$

Where, P is the pressure developed to rupture fruits (1866.232N/m^2), F is the required force (675 N) and A is the cross sectional area of the inner perforated cylinder of the extracting chamber (0.362m^2).

2.3.2 Design of Extraction Chamber

During loading and extraction process, the internal cylinder would develop a stress which would cause efficient compression of juice. Equation (7) was used to calculate the maximum stress during compression as expressed by Aremu and Ogunlade (2016)

$$\acute{y} = \frac{P_r}{4t} \qquad (7)$$

where, $\acute{y}$ is the maximum shear stress the cylinder will be subjected to failure by yield (for steel, ultimate yield stress with a factor of safety of 2 is 70MN/m^2), P is the internal pressure of cylinder (35MN/m^2), r is the internal radius of cylinder (0.0575 m), t is the thickness of cylinder (13 mm).

2.3.3 Power Requirement

It was assumed that an adult with an average power of 0.075kW should be able to handle the manual juice extractor. Equation (8) shows the formula for the required power for compression process as stated by Aremu and Ogunlade (2016)

$$P = 2\pi NT \qquad (8)$$

where; P is the power required, N is the speed (45 rpm), T is the turning moment (121.50 Nm).

2.4 Machine Fabrication and Assembly

After the design, the machine was fabricated and assembled according to designed specifications using workshop tools, machines and standard procedures. The cost of producing the machine was ₦28,500.

2.5 Performance Evaluation of the Machine

Sweet orange (*Citrus sinensis*)-**SO**, watermelon (*Citrullus lanatus*)-**WM**, red apple (*Malus pumila*)-**RA**, green apple (*Malus domestica*)-**GA**, pineapple (*Ananas comosus*)-**PN**, lime (*Citrus aurantifolia*)-**LI**, lemon (*Citrus limon*)-**LM** and grape (*Citrus paradisi*)-**GP** were purchased at Food Commodity market in Ilorin, Kwara State Nigeria. The fruits were sorted, graded, washed, peeled and cut into pieces.

The performance evaluation of the machine was carried out by introducing a constant mass of 200g of each fruit into the extraction chamber where the fruits were crushed and compressed under the application of a compressive force thereby forcing the juice out of the fruits. For each fruit, five replicates were used. Equations (9-12) shows the formula for the performance indices considered during the extraction process.

$$\text{Juice yield} = \frac{100\,W_{JE}}{W_{JE} + W_{RW}}\% \qquad (9)$$

$$\text{Extraction efficiency} = \frac{100W_{JE}}{XW_{FS}}\% \qquad (10)$$

$$\text{Extraction loss} = \frac{100[W_{FS} - (W_{JE} + W_{RW})]}{W_{FS}}\% \qquad (11)$$

$$\text{Extraction capacity} = \frac{weight\ of\ juice\ (g)}{time\ taken\ (min)} \qquad (12)$$

Where, W_{JE} = weight of juice extracted, W_{RW} = weight of residual waste, W_{FS} = weight of feed sample. X = juice constant of the fruit in decimal (0.77- 0.80) for all the fruits used. The calculated results of juice yield extraction efficiency, extraction loss and juice yield of the fruits were presented graphically using Microsoft Excel (2013 version)

3. Results and Discussion

The result of performance evaluation (juice yield, extraction efficiency, juice content, extraction loss and extraction capacity) is shown in Fig. 3. Pineapple had the highest juice yield and extraction efficiency of 68.74% and 82.99% which is closely followed by water melon with 63.35% and 76.46% respectively.

In the citrus family, sweet orange possessed the highest juice yield of 51.28%; a distant value from that was obtained for grape, lemon and lime with juice yields of 31.54%, 42.58% and 22.53% respectively. The extraction loss using the manually-operated multipurpose fruit juice extractor was higher in fruits with higher juice yield especially watermelon and pineapple with values of 5.12% and 3.35% respectively. Low juice content was obtained for lime with a value of 22.02% while the highest juice content of 66.40% was obtained for pineapple. Aremu and Ogunlade (2016) evaluated a portable multi-purpose juice extractor and reported juice yield value of 45 and 46.5, 55.3% for orange, pineapple and watermelon respectively. These values were lower than obtained values for orange, pineapple and watermelon fruits using the machine developed in this current research. The reason behind the observations may be attributed to physiology of fruits, species, maturity stage, natural moisture content at the time of harvest, antecedent storage and handling conditions before juice extraction process and season at which the fruits were procured.

Aviara et al. (2013) developed and carried out the performance evaluation of a motorized fruit juice extractor. Values of 96.9%, 94.3%, and 96.6 % for extraction efficiencies of peeled pineapple, oranges and water melon were obtained respectively. Also, Abulude et al. (2013) obtained 83.86 and 85.38% for the extraction efficiency of orange and pineapple respectively while a manually-operated cashew juice extractor by Lucas and Ogunsina (2015) gave an average juice extraction efficiency of 85.38%.These higher values may be as a result of mode of operation (manual or mechanical), size or capacity of the machine and technical know-how level of the operator. Adebayo, Unuigbe and Atanda (2014) obtained an extraction loss of 12.50% using a portable motorized pineapple juice extractor. Pineapple and lime had the highest and lowest extraction capacities of 92.85 and 29.81 (g/min) respectively.

In comparison to a manually-operated juice extractor developed and evaluated by Abulude et al. (2007) where extraction capacities for pineapple and orange were 1.32 kg/h and 1.29 kg/h respectively. The current developed manually-operated multi-purpose juice extractor has higher extraction capacities for pineapple (92.85 g/min) and sweet orange (79.26 g/min) when compared with that of Abulude et al. (2007). Possible reasons may be associated to the initial juice content present in fruits and characteristics of fruits such as size and species of fruits.

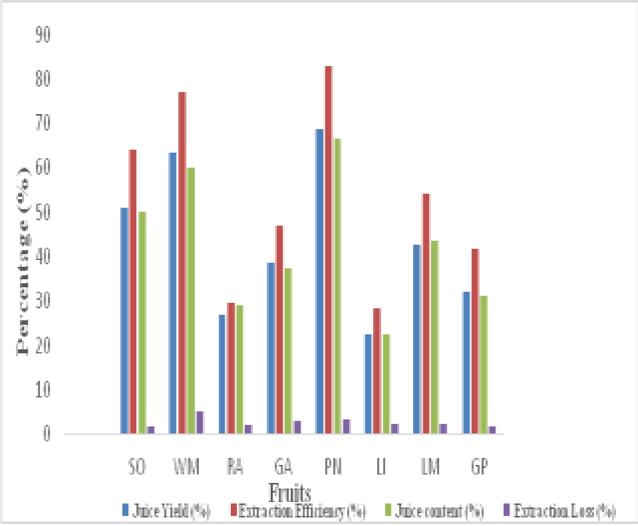


Fig. 3: Performance indices of the Manually-operated Multi-purpose Fruit Juice Extractor

***(Note:** 1st bar-Juice Yield, 2nd bar-Extraction Efficiency, 3rd bar-Juice Content and 4th bar-Extraction Loss)*

4. Conclusion

Development and performance evaluation of a simple to operate and maintain manual multipurpose fruit juice extractor was done. Results obtained from the performance evaluation of the machine showed that pineapple had the highest values of juice yield (68.74%), juice content (66.40%), extraction capacity (92.85 g/min) and extraction efficiency (82.99%); while sweet orange and lime had the lowest extraction loss and extraction capacity of 1.67% and 29.81 g/min respectively.

References

Abulude, F. O., Elemide, A. O., Ogunkoya, M. O. & Adesanya, W. O. (2007). Design and performance evaluation of a juice extractor constructed in Nigeria. *Research Journal of Applied Sciences*. 2(1), 31-34.

Adebayo, A. A., Unigbe, O. M. & Atanda, E.O. (2014). Fabrication and performance evaluation of a portable motorized pineapple juice extractor. *Innovative Systems Design and Engineering*. 5(8), 22-29.

Aremu A.K. & Ogunlade, C.A. (2016). Development and evaluation of a multipurpose fruit juice extractor. *New York Science Journal*, 9(6), 7-14.

Aviara, N. A., Lawal, A. A., Nyam, D. S. & Bamisaye, J. (2013). Development and performance evaluation of a multi-purpose juice extractor. *Global Journal of Engineering, Design and Technology*, 2(2), 16 -21.

Bates, R. P. & Crandall, P. G. (2001). Principles and practices of small- and medium- scale fruit juice processing. FAO, Agricultural Services Bulletin, Rome

Hall, A.S., Holowenko, A.R. & Laughlin, H.G. (1987). *Theory and Problems of Machine Design. Schaum's outline series*. New York: McGraw-Hill Book Co.

Ogunsina, B.S. & Lucas, E.B. (2008). Development of a manually-operated cashew juice extractor. *Agricultural Engineering International: The CIGR E-journal Manuscript*, FP 07 037. Vol X.

Oguntuyi, V. F. (2013). Evaluation of development and performance of a manually-operated orange juice extracting machine. *International Journal of Research Development*. 2(1), 257-264.

Olaniyan, A. M. (2010). Development of a small scale orange juice extractor. *Journal of Science and Technology*. 47(1), 105-108.

Reinhold, V. N. (1986). Ergonomic design for people at work, Vol. 2, Eastman Kodak Company

Sylvester, A.A. & Abugh, A. (2012). Design and construction of an orange juice extractor, *Proceedings of the World Congress on Engineering*, July 4 - 6, London, U.K.