GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
www.gifre.org

DEVELOPMENT AND PERFORMANCE EVALUATION OF A MULTI-FRUIT JUICE EXTRACTOR

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Abstract

A multi-fruit juice extractor was designed, constructed and evaluated for performance using pineapple, orange and melon fruits. The machine was designed to operate on the principle of compressive and shear squeezing force exerted through an auger conveying system. It consists of a tool frame, juice extraction encasement, screw conveying tapered shaft, perforated screen base, collection chute, gear box, and electric motor. 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 pineapple, orange and water melon that were introduced into the machine as peeled or unpeeled fruits. The performance indicators considered were percentage juice yield, extraction efficiency and extraction loss.

Results of performance analysis showed that type of fruit and peel condition significantly influenced the performance indices at 1 % level of significance. Percentage juice yield for peeled and unpeeled pineapple, orange and water melon was 79.1 and 68.7 %, 77 and 69.2 %, and 89.5 and 89.7 % respectively. Extraction efficiency was respectively 96.9 %, 94.3%, and 96.6 % for peeled pineapple, oranges and water melon, and their respective unpeeled value was 83.6 %, 84.2 %, and 97.1 %. The extraction loss of peeled and unpeeled fruits was respectively 2.1 and 2.7 % (pineapple), 2.1 and 2.5 % (orange), and 2.9 and 2.6 % (water melon). The machine is simple to operate and maintain, therefore it is recommended for small holder and local fruit juice processors.

Keywords: *Fruits, extractor, juice yield, extraction efficiency, extraction loss, juice constant.*

1. Introduction

Fruit can be defined as ripened ovaries of plants containing seed. This organ is important mainly for its edible fleshy component which serves to protect and nourishes the seed(s) it contains. The fleshy component has been reported to have adequate quantities of water, sugars, vitamins (A and C), and dietary fibre (Taylor, 1999; Bates et al. 2001), therefore it is used in complementing the diet that is lacking in staple food. However, the high rate of deterioration and percentage loss, 30 to 50 % of tropical fruit reported in Nigeria (Aworh 1988) have limited their availability all the season round. Thus, the effect of these limitations on availability of fresh fruits can be eliminated if juice extracted from fruits is considered as an alternative to fresh fruit. Fruit juice is the extractable fluid contents of cells or tissues (Meriam-webster 1981). Kazambe (2005) reported that fruit juice is the next best thing to fresh fruit.

Traditional methods are still employed in the extraction of juice from fruit. These involved macerating fruit with hand or peeling, slicing, blending and pressing the fruit. These methods are not only energy sapping and time consuming, but also yield low quantity juice and are unhygienic. Thus traditional method of juice extraction cannot be employed for small to medium scale production to meet local commercial need. Therefore to meet this demand, there is need to develop a small to medium size mechanical device that is capable of extracting juice from a number of tropical fruit crops.

Badmus and Adeyemi (2004) designed and fabricated a small scale whole pine apple fruit juice extractor. The machine consisted of beater blades and a shaft in conjunction with a powered screw pressing mechanism. The machine processed successfully 12 kg of ripe pineapple fruit into 8 litres of pineapple juice. Kasozi and Kasisira (2005) developed a banana juice extractor that operated on the principle of impact and friction due to the action of a mixer on banana-grass mixture and rough wall of extraction chamber and obtained a juice extraction efficiency of 47 %. Oyeleke and Olaniyan (2007) tested a small-scale motorized multi-juice extractor developed in India to determine juice yield of orange, grape, tangerine, water melon and pine apple and obtained extraction efficiency of at least 81.3 %. Olukunle et al. (2007) developed a system for fresh fruit extraction and dispensary. The system worked on the principle of shearing, impacting, and squeezing from knife, nails brush and wire brush for washing, peeling, extracting and filtering. The unit cost of this system is 1,500 US dollars which could not be affordable to small-scale processors. This study was therefore carried out to design, construct and evaluate the performance of a multi-fruit juice extractor.

2. Materials and Methods

2.1 Design Consideration

The engineering properties of the processed fruits that are relevant to the design, development and performance evaluation were considered. The properties include crushing strength, moisture content, size of feed, true and bulk densities. Other factors considered were strength of machine components, cost of construction, ease of operation and maintenance and energy requirement.

2.2 Design of Machine Components

Since the extractor works on the principle of compression and shear, selection of materials and sizes of machine components were base on stress/strain analysis.The diameter and thickness of the conveyor housing was designed using the following equations respectively:

$$D = \sqrt{\frac{4}{\pi} \times \frac{Q}{v}} \quad (1)$$

$$T = \frac{P \times D}{2\delta_t} \times c \quad (2)$$

where D is the internal diameter in mm of the conveyor housing, Q is the mass flow rate in g/min, v is the linear velocity in mm/min, c is material constant, P is internal pressure in Pa and δt is stress in Pa.

the diameter of the shaft of the screw conveyor was obtained from the following expression:

$$d = \sqrt[3]{\frac{16T}{\pi\tau_{max}}} \quad (3)$$

where d is the thickness of the shaft in mm, T is torque in Nmm, τ_{max} is maximum shear stress in N/mm.

The length of the screw of the screw conveyor was also determined using the following expression used by Oyinlola et al. (2004):

$$S = 3.4203\ (r + ml)\ n\pi \quad (4)$$

and m = tanβ, where S is length of screw in mm, r is radius of shaft in mm, β is angle of roll, l length of shaft in mm and n is length of belt was also determined using the following equation

$$L = \frac{\pi}{2}(d_2 + d_1) + 2x + \frac{(d2-d1)^2}{4x} \quad (5)$$

where L is length of belt, d_2 is diameter of driven pulley, d_1 is diameter of driving pulley, x is distance between the pulleys.

Sizes of pulley and gears were determined using expression of power transmission ratio.

2.3 Machine Description and Operation

The juice extractor was designed to work on the principle of compression and squeezing due to the gradual reduction of clearance between conveyor housing and screw conveyor. It is made up of five units, namely tool frame, feed hopper, juice extraction unit, collecting unit, and power and transmission unit (Figure 1).

Figure 1. Photograph of the multi-fruit juice extractor.

The tool frame is made up of low carbon steel having an angle cross-section. The tool frame forms a rectangular shape of 985 mm × 310 mm × 620 mm. It supports and holds the machine components, and gives it a compact design and a sturdy outlook.

The feed hopper, which is mounted on top of the juice extraction barrel, is trapezoidal in shape and inclined at an angle that enabled mass flow of feed into the extraction chamber to be achieved. The hopper has rectangular upper and base openings of 340 mm × 340 mm and 80 mm × 80 mm respectively. It is made of galvanized metal sheet of 1.5 mm thickness.

Below the feed hopper base and mounted on the tool frame, is the barrel like juice extraction unit that formed a conveyor housing of 100 mm diameter and 420 mm length, where juice extraction takes place. Through this housing runs a shaft tapered from 79 mm to 56 mm diameters from one end to the other end and rolled round it is a tapered screw. The shaft and screw assembly known as screw conveyor receives power via the reduction gear box and runs in a journal bearing. The screw on the conveyor is 77 mm apart on the shaft and tapered from 12.5 mm at the feed entry point to 10.5 mm at the discharge end. The screw conveyor and housing provide the shear and compressive forces needed to crush the fruit and squeeze out the juice.

At the bottom of the extraction chamber, is a perforated concave screen made of stainless steel. It permits the juice extracted from the fruit to be filtered from the crushed fibre. The filtered juice dropson an inclined juice collection channel and flows down into the juice collector. The waste discharge chute is located at the end of the extraction run.

The power unit consists of a 2 hp 1428 rpm electric motor that rotates at 1428 rpm, which powers the machine via a belt, pulleys and gear box arrangement. The motor is mounted on a seating located at the base of the tool frame. The gear box is powered by a shaft on which a pulley of 380 mm diameter is mounted and driven by a belt which receives power from a pulley mounted on the motor shaft. The orthographic view and part list of the multi-juice extractor are presented in Figure 2.

The first step to be taken in order to operate the juice extractor is to reduce the size of fruit whose juice is to be extracted into smaller sizes and fill the hopper with the sliced fruit. The motor is started by switching on the main switch and power is transmitted through the belt, pulleys and gear box to rotate the screw conveyor. As the screw conveyor rotates within the conveyor housing the screw collects the sliced fruit from the base of the hopper and moves them through the extraction chamber toward the collection point. During this movement, the sliced fruit is crushed and juice is squeezed out due to the gradual reduction of gap between the conveyor housing and screw conveyor. The juice extracted is filtered through a screen and channel into a juice collector, while the waste is channel through the waste collector.

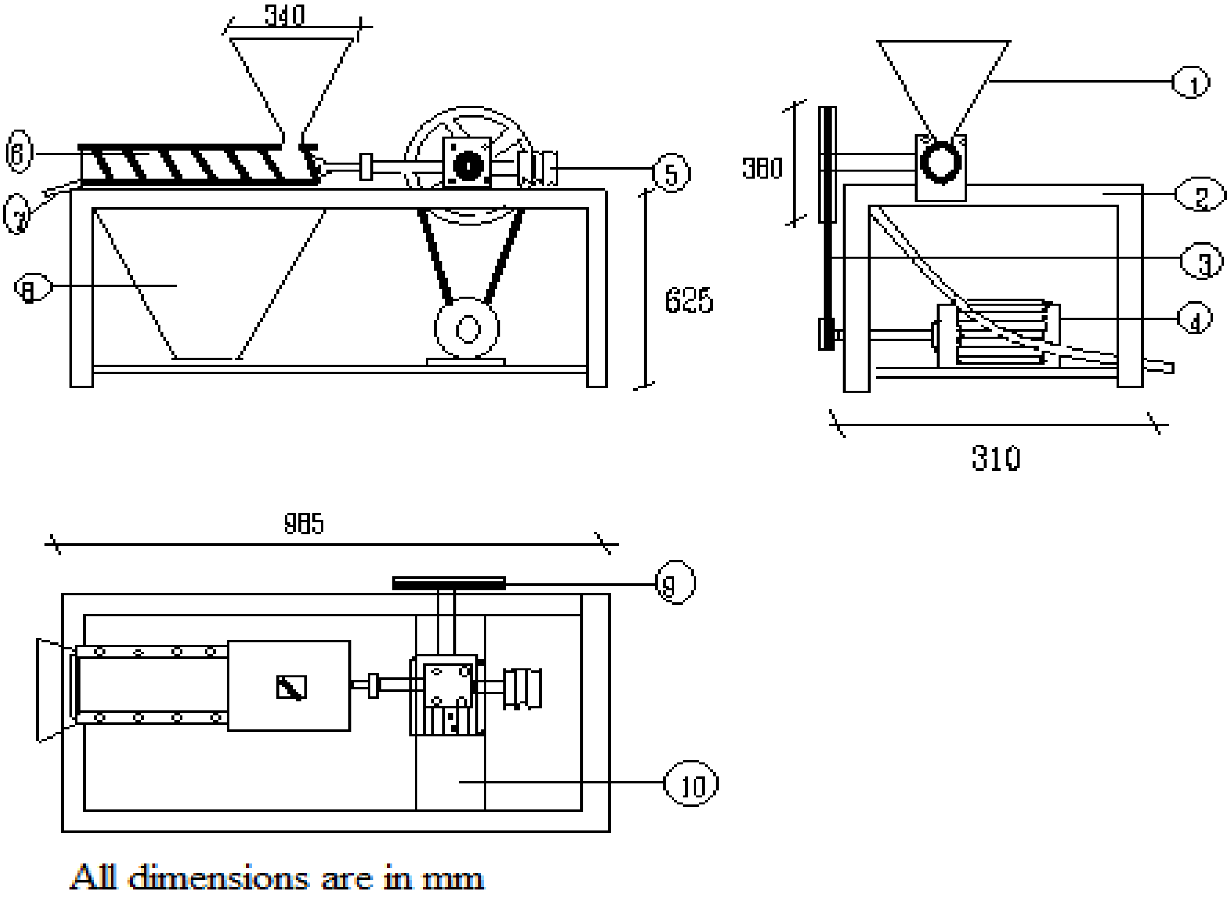

Figure 2. Multi-juice applicator in orthographic views (1)Hopper, (2) Tool frame, (3) V-belt, (4) Electric motor, (5) Flywheel, (6) Extraction chamber, (7) Waste chute, (8) Juice Drain, (9) Pulley and (10) Flat bar

2.4 Bill of Engineering Measurement and Evaluation of Production

The cost of producing the extractor is presented in Table 1. This comprises the cost of components bought, cost of materials and parts fabricated and cost of machining and non-machining jobs.

Table 1: Bill of engineering measurement and evaluation of a unit of juice extractor

S/No.	Component	Material	Specification	Cost (NGN)
1.	Hopper	Galvanized iron sheet	200 × 120 × 230 mm	6000.00
2.	Conveyor housing	Galvanized Arco pipe	92 mm diameter and 430 mm length	10,000.00
3.	Frame	Angle iron	50 × 50 mm standard length	10,000.00
4.	Shaft	Iron shaft	79 mm diameter and 430 mm length	10,000.00
5.	Sieve	Stainless steel		2000.00
6.	Special parts			
		V-belt	A64	300.00
		Cast iron pulley	380 mm diameter	400.00
		Grinding plate	power flex	
		Cutting disc	Power flex	
		Flat bars	10 mm thick	2,000.00
		Reduction gear box	1:20	8,000.00
		Coupler		1,500.00
		Electric motor	2 hp	10,000.00
		Bolts, nuts and washers	M 19 and M 13	300.00
7.	Working items	Welding	Gauge 10 ordinary	1000.00
		Electrodes	Gauge 12 stainless	500.00
		Paint	Blue	7,000.00
8.	Labour			7,000.00
9.			Total	70,000.00

2.5 Performance Tests and Evaluation

Bulk quantities of orange, pine apple and water melon were purchased from a local store in Maiduguri, Borno State, Nigeria. The fruits were cleaned, sorted and damaged ones were discarded. The undamaged ones were divided in to two samples from each type of fruit. The first samples were peeled and reduce in size, while the second samples were size reduce without peeling.

The machine performance test was carried out by pouring a known mass of fruit into the hopper. The power source was switch on to run the electric motor, which in turn powers the machine. The fruit in the hopper were then delivered in to the extraction chamber and the machine was allowed to operate until the material was completely fed and extracted. After that, mass of fruit fed into the machine, mass of juice extracted, mass of residual waste and juice constant of the fruit in decimal were recorded. The juice constant was obtained from the ratio of sum of masses of juice extracted and juice in chaff to the mass of fruit fed in. The mass of juice in chaff was determined using the method of ASAE (1983) as applied by Aviara et al. (2008), and Oje (1993). This involved oven drying the chaff at 130°C until a constant weight was reached. Each experiment was replicated three times for both peeled and unpeeled pine apple, orange and water melon.

The performance evaluation of the juice extractor was carries out on the basis of the following indices used by Tressler and Joslyn (1961)

i. Juice yield, $J_y = \frac{100\ W_{JE}}{W_{JE} + W_{Rw}}\ \%$ (6)

ii. Extraction efficiency, $E_e\% = \frac{100 \times W_{JE}}{x\ W_{FS}}\ \%$ (7)

iii. Extraction loss, $E_l\ \% = \frac{100\,[W_{FS} - (W_{JE} + W_{RW})]}{W_{FS}}\ \%$ (8)

where W_{JE} is mass of juice extracted in g, W_{RW} is mass of residual waste in g, W_{FS} mass of feed sample in g and x is juice constant of fruit in decimal.

Analysis of Variance (ANOVA) was used to determine the extent to which the type of fruit and peel condition affected the performance indices.

3. Results and Discussion

The juice constants for peeled and unpeeled pineapple, orange and water melon were respectively found to be 0.8 and 0.78, 0.78 and 0.76, and 0.91 and 0.88. These values of the juice constant determined were used in equation (7) to calculate the extraction efficiency.

The results of percentage of juice yield, extraction efficiency and extraction loss for peeled and unpeeled pineapple, orange and water melon are presented in Table 2.

Table 2. Variation of percentage juice yield, extraction efficiency and extraction loss with type of fruit and fruit peel conditions.

Performance index	Peeled			Unpeeled		
	Fruit Type			Fruit Type		
	Pine apple	Orange	Water melon	Pine apple	Orange	Water melon
Juice yield (%)	79.13 (0.12)	77.03 (0.25)	89.53 (0.15)	68.70 (0.00)	69.10 (0.10)	89.72 (0.47)
Extraction efficiency (%)	96.93 (0.06)	94.23 (0.25)	96.6 (0.00)	83.57 (0.06)	84.23 (0.06)	97.08 (0.12)
Extraction loss (%)	2.13 (0.25)	2.10 (0.10)	2.90 (0.18)	2.70 (0.00)	2.47 (0.15)	2.61 (0.42)

Numbers in parenthesis are standard deviation.

From Table 2, it can be seen that juice yield for peeled fruits were relatively higher than that of unpeeled fruits. The effect of fruit type and peel condition were found to have significant effect on juice yield (Table 3). For peeled fruits, water melon had the maximum juice yield followed by pineapple and orange respectively, while pineapple had the minimum value for unpeeled fruits. These results were similar to those reported by Oyeleke and Olaniyan (2007). The variation of juice yield with extractor feed rate presented in Table 4 shows that feed rate had no significant effect on juice yield. These results indicate that fruit parameters such as type of fruit and peel condition have significant effect on juice yield than such machine parameter as feed rate. Thus juice yield ability of the extractor could depend on the fibre and/or dry-matter composition of a fruit.

Table 3: F-ratio and P-value for the results of machine performance tests

Source of variation	F-ratio			P-level		
	Juice yield	Extraction Efficiency	Extraction loss	Juice yield	Extraction efficiency	Extraction loss
Fruit type (FT)	13658.6	18669.4	13.96	0.000	0.000	0.0157
Fruit peel condition (FPC)	5842.88	133362.1	5.79	0.000	0.000	0.0529
Interaction (FT*FPC)	1634.98	3994.21	6.99	0.000	0.000	0.0271

The extraction efficiencies of peeled pineapple and orange were relatively higher than those of their respective unpeeled fruits (Table 2). Water melon however showed no significant difference on extraction efficiency between peeled and unpeeled fruit. For peeled fruits, pineapple had the maximum extraction efficiency followed by water melon and orange, while water melon and pineapple had respectively the maximum and minimum values for unpeeled fruit. The effect of fruit type and peel condition on extraction efficiency was significant at 1 % level of significance. The material feed rate had no significant effect on extraction efficiency. This also underscores the effect of fruit type and fruit peel condition on the extractor performance indices of juice yield and extraction efficiency.

The result of extraction loss presented in Table 2 shows that water melon had maximum extraction loss for peeled fruits, while pineapple had the maximum value for unpeeled fruits. For both peeled and unpeeled fruits orange had the minimum extraction loss. The F-ratio and P- value of extraction loss in Table 3 indicated that type of fruit significantly affected extraction loss at 5 % level of significance, while extraction loss was not significantly affected by peel condition.

Table 4: Variation of juice extractor performance indices with material feed rate

Fruit peel condition	Type of fruit	Feed rate g/min	Extractor performance index		
			Juice yield	Extraction efficiency	Extraction loss
Peeled	Pineapple	228.6	79.0	96.9	1.9
		263.2	79.2	96.9	2.1
		268.8	79.2	97.6	2.4
	Orange	208.3	76.8	94.1	2.0
		219.8	77.0	94.2	2.1
		227.3	77.3	94.5	2.2
	Water melon	288.5	89.4	96.6	2.8
		294.1	89.5	96.6	2.8
		299.4	89.7	96.6	3.1
Unpeeled	Pineapple	217.4	68.7	83.6	2.7
		222.2	68.7	83.6	2.7
		238.4	68.7	83.5	2.7
	Orange	168.5	69.1	84.3	2.5
		172.4	69.0	84.2	2.4
		176.1	69.2	84.2	2.6
	Water melon	245.9	89.2	97.0	2.1
		250.0	89.9	97.0	2.8
		252.5	90.1	97.2	2.9

4. Conclusions

A multi-fruit juice extractor was designed, constructed and tested. The extractor was designed to extract juice based on the principle of compression and shear due to the action of conveyor housing and screw conveyor. 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 water melon, pine apple and orange.

References

Aviara, N. A., Stittu, S. K. and Haque, M. A. (2008). Development and performance evaluation of a guna seed extractor. Agricultural Engineering International; CIGR Ejournal, Manuscript PM 07 036, 10:1-20.

Aworh, O.C. (1988): Storage and processing of fruit, vegetables and oil seeds. Agro-based Industrialization Seminar Paper. Administrative Staff College, Lagos, Nigeria.

Badmus, G. A. and Adeyemi, N. A. (2004). Design and fabrication of a small scale whole Pineapple fruit juice extractor. Proceedings of the Nigeria Institution of Agricultural Engineers, 26: 285-291.

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

Kasozi, G. and Kasisira, L. L. (2005). Design and performance of a banana juice extractor.African Crop Science Conference Proceedings, &: 1381-1384.

Kazembe, H. W. (2005). Approaches to successful development of low-cost fruit juice extraction technologies. A case study to improved rural livelihood in Malawi. Stuttgart Hohenhein, Conference on International Agricultural Research for Development.

Merriam Webster (1981). Webster's Third International Dictionary.

Oje, K. (1993). Some engineering properties of thevetianut. Journal of Agricultural Engineering and Technology, 1: 38 – 45.

Olukunle, O. J., Oguntunde, P. G. and Olukunle, O. F. (2007). Development of a system for Fresh fruit juice extraction and dispensary. Conference on International Agricultural Research for Development.

Onyilola, A., Ojo, A. and Adekoya, L. O. (2004). Development of a laboratory model screw Press for peanut oil expression. Journal of Food Engineering, 64(2): 221-227.

Oyeleke, F. I. and Olaniyan, A. M. (2007). Extraction of juice from some tropical fruits using a Small scale multi-fruit juice extractor. African Crop Science Conference Proceedings, 8: 1803-1808.

Taylor, J. K. (1999). Fruits and vegetables, Oxford pergaman fruit. National Seminar on Fruits and Vegetables, Texas.

Tressler, D. K. and Joslun, M. A. (1961). Fruit and Vegetable Juice Technology. AVI Publication Co. Inc, West port, Connecticut, 155-156.