Design, Development and Performance Evaluation of Semi Automated Citrus Juice Extractor Machine

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ABSTRACT
Citrus juice extractor machine has been design, fabricated and can be found in numerous studies at different areas. These citrus juice extractor machine is a semi automated one that operates from the entrance of citrus into the hopper basket till the filteration of the juice for consumption. The operational procedure for the extraction of juice starts from the stacking of neatly cleaned citrus of same size in the basket position ontop of the extractor machine which in turn passes through the hopper to the extraction chamber where the oranges are cut into two equal halves for the twin knaggy ball shearing then the pulps are dropped through the remaning collector to the residue collection bin while the extracted juice flows through the seize to a container for consumption. The optimal operating speed of the juice extraction machine was found to be 15rpm, while the optimum feed was found to be F_1 (2.5 kg/min). The average juice extraction efficiency at optimum speed (S) and feed rate (F) was 64%; juice yield at optimum Speed and Feed was 60%; juice extraction losses was 35% at optimum Speed and Feed.

Keywords*: remaining collector, top basket hopper, juice extraction chamber, knaggy ball*

I. INTRODUCTION

Citrus plants are grown and cultivated in most parts of world with north eastern India as the originators [1]. The world production of oranges was led by Brazil, China, India, EU, USA, Mexico, Egypt as the largest producers in 2019-2020 projected as 76 million metric tons (84 million short tons), [2]. The fiscal Year 2020/2021 showed Brazil as the leading universal orange producer, with production volume of 14.7 million metric tons against the overall production volume of fresh oranges summed to about 47.45 million metric tons which is expected to increase to 47.8 million metric tons in 2022/2023 [3], The Year 2022/2023 projection shows that the top ten citrus producing counties are Brazil, China, European Union, Mexico, United States, Egypt, Turkey, South Africa, Morocco and Vietnam [4]. Due 140 countries were reported to be involved in citrus production [5]. The fruit is in abundant during its harvesting period and always in short supply and expensive during its off season with about 30% loss of the fresh fruit [6]. Attempts to store these fruits in its fresh and natural form have been fruitless as a result of its perishable nature evident in its elevated moisture content, deplorable post-harvest management and marketing approach [7]. Research conducted on the physical properties of orange using reasonable quantities that is above hundred revealed that the mass of the orange fruit ranges between 160 - 170g [8 – 9]. Orange in its natural form has shelf life between 2-10 days but it can still be improved upon by storing in a proscribed temperature or pressure, procession into more established products like juices, jellies and jam, refrigeration, packaging in plastic films, use of food surface coatings, chemical treatments and irradiation [10-11]. However, the cost of the fruit is so little as to compensate for the cost of using this method in countries like Nigeria [12].

Fruit processing into juice is adjudged to be an improved way of storage, preservation and value addition. Juice extraction and separation thus becomes a new market opportunity for modern consumption of fruit products. Orange extraction evolution commenced by hand extraction of the juice which is quite dawdling, tiresome and unhealthy; while the demand for juice consumption increases by machine extractor existence [13]. The juice extraction machines have the benefits of less time usage, enhanced efficiency, improve juice yield and less waste and junk [14]. Locally fabricated juice extractors have existed but have its shortcoming in terms of limited output [15]. These juice extractor is an improved extractorl machine which utilizes

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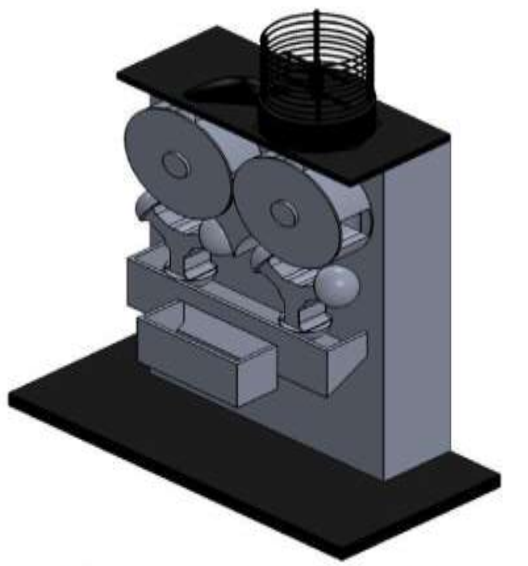
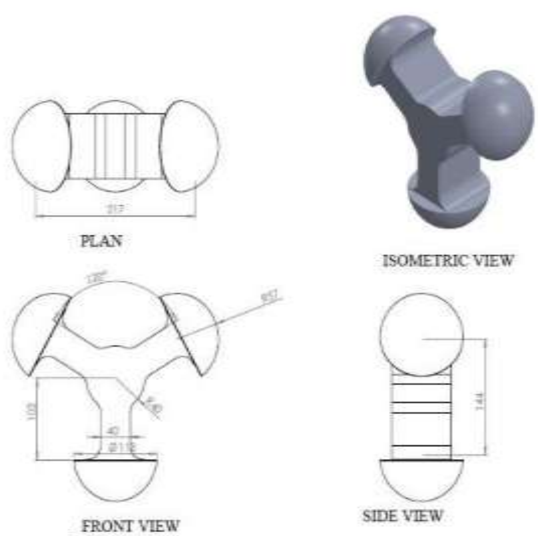
the pressing means to extract juices from some citrus fruit [16]. Citrus (oranges) and citrus yield have enriched nutritional contents; that are rich and inexpensive sources of vitamins (particularly vitamin C), minerals and dietary fiber required for healthy living [17]. Fruit juices are the extracted tissues fluid content of the fruit or the extraction of fermentable fluids of the fruit for the use of human beings, through mechanical process from entirely nutritional fruits [10].

Agricultural mechanization is a sure way to boosting home-grown design, invention and manufacture of most machines and equipment required for technology advancement [18]. Although, different size and shape of citrus fruits exist, but there is amazingly little or no basic disparity in the extraction process of juice from them [16]. To address this problem there is an urgent need to design and fabrication an automated fruit juice extractor appropriate for this range of fruits for commercial needs of the farmers and the majority of our teeming populace [17]. This developed juice extractor machine will be a simple, reasonably priced machine that is eco-friendly, energy efficient and flexible in the processing of citrus fruits. This machine outcome will provide local substitute to imported brands of processed fruit juices machines and also reduction of wastage during the citrus harvest seasons.



ISOMETRIC VIEW OF JUICE EXTRACTOR

Figure 1: Solid work Design of Juice Extractor Machine



ISOMETRIC AND ORTHOGRAPHIC VIEW OF ROLLER

Figure 2: Exploded view of the Extraction Chamber

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II. DESIGN CONSIDERATIONS AND CALCULATIONS

The machine is fabricated such that it will remain stable while in operation. It consists of electric motor, hopper, orange remaining collectors, shafts, Knaggy rotary balls, gears, waste outlet, juice outlet and main frame. The juice extractor design works on three principles: convey, slice and squeeze. The machine components are held and supported by a rectangular shape main frame formed to give a compact design and stronger outlook. The hopper is mounted on top of the extraction chamber. This feed hopper is circular in shape and attached to a shaft to enable it feed the oranges into extraction chamber of the machine. perforation placed below the two knaggy balls at the extraction chamber. The already squeezed orange halves are trashed through the pulp outlet as residual waste on both sides of the machine. The diagram in figures 1- 4 explains the operational sequence of the orange juice extractor machine.

An orange juice extractor has many components, each of which contributes to the overall performance and ultimately affects the operational results. Good choice of material and well-designed components that are complementary to each other will keep the overall performance within an acceptable limit. Selecting suitable materials for the various machine components is one of the most important tasks in the design.The decision of what materials to be used was made before the actual dimensions of the parts were determined since load and stress calculations are based on the properties of the materials. Along with the choice of a material, the process which the material would be formed into the machine was also considered. Although, a given material may have the required properties for satisfactory service but it is also important to decide on the forming/shaping process of the machine part as the two combined determines the cost of the part or machine and represents the maximum value of money to be expended.

As important as the stress and deflection of mechanical parts are, the selection of a material is not only based upon these factors alone. Other factors that are considered for a satisfactory material selection are weight, thermal properties, resistance to corrosion, resistance to wear, availability, cost, appearance, safety and ease of fabrication. The various properties and functions of each component in the machine determine the choice of material for its construction. For the machine housing, stainless steel is used.The whole machine can be described in three compartments namely: carrier (hopper), Extracting chamber and Frame as shown in solid model of figure 1. The main function of the frame in the design of the extractor machine is its provision of the appropriate relative position of the units and component parts mounted on it over all working conditions and period of service. The strength of the machine is the second required consideration made in the design of the extractor machine. The frame structure was design to accommodate different weights of components mounted on it, and it is made of mild steel with overall dimension of 393mm × 220mm × 581mm. The hopper (item A) in figure 1 is an essential part of the machine that guides and retains fruit to be processed. It acts as a container and at the same time helps in the gradual introduction of the orange fruit into the juice-extracting chamber. The circular shaped hopper is located on top of the housing. Galvanized metal sheet was used for the "hopper" all the same stainless steel or alloys of aluminum can substitute.

The juice extraction is carried out as shown in figure 4, extraction chamber. It consists of the orange collector and rotary balls which are arrange on the shaft along its length alternatively. It also consists of the knife that cut the oranges in two equal halves. The knife is situated at the center of the two orange collectors. Furthermore, the juice collector and sieve are also located in this compartment. The sieve filters the juice while the collector collects it into the cup. For better filtering it is expected that sieves should be changed after each day of operation. The other components of the extractor include: Shafts, Gears (spur gears) and chain drivers, Electric motor which rotates the shaft connected to the knaggy balls, Bearings, Sieve for juice filtration after extractor, Waste separator for separating the chaff from the juice being extracted, Switch: For turning the machine ON/OFF Rotary balls for pressing and extracting the orange juice. Shaft is a rotating member of the machine, see figure 1 (item D). Mild steel or galvanized steel can serve as the material for shaft. The press components (orange collectors and rotary balls) which are of the same material (Teflon material or wood were mounted on the shaft, set alternatively and evenly at equal intervals along its length. The shafts are seven out of which six carries spur gears of the same number of teeth while the seventh carries bevel gear for the hopper which has lesser number of teeth. The bevel gear engages with another bevel gear attached on one horizontal shaft. The six gears are arranged in parallel, with three gears on each side. Two orange collectors and two rotary balls are driven by two other gears that transmit torque to the gears on the shaft of orange collector and rotary balls

Rotary balls are made up of Teflon material but wood can also be used. Each consists of three balls on a single axis of 1200 from each other and radius of 57 mm balls attached at the ends. The length and size of the rotary balls is tantamount to the size of the compressing chamber (collector). For effective pressing two pairs of rotary balls were developed. The weight of the hopper, shaft, gears, housing structure are been carried by the machine base and support. The frame is made with 5mm×5mm angle iron with height of 40mm and having an area of 25600 mm2 in order to support the machine and hold it firmly when it is working. The motor base was made from angle iron of mild steel material. The bars were cut to dimension and welded carefully to desired shape with fixation points made on it.

The orange collector is a circular shaped object, constructed with a Teflon material or wood; it is two in number with each having three doom shaped recesses that collects the orange. The collector has a height of 100 mm and radius of 73 mm

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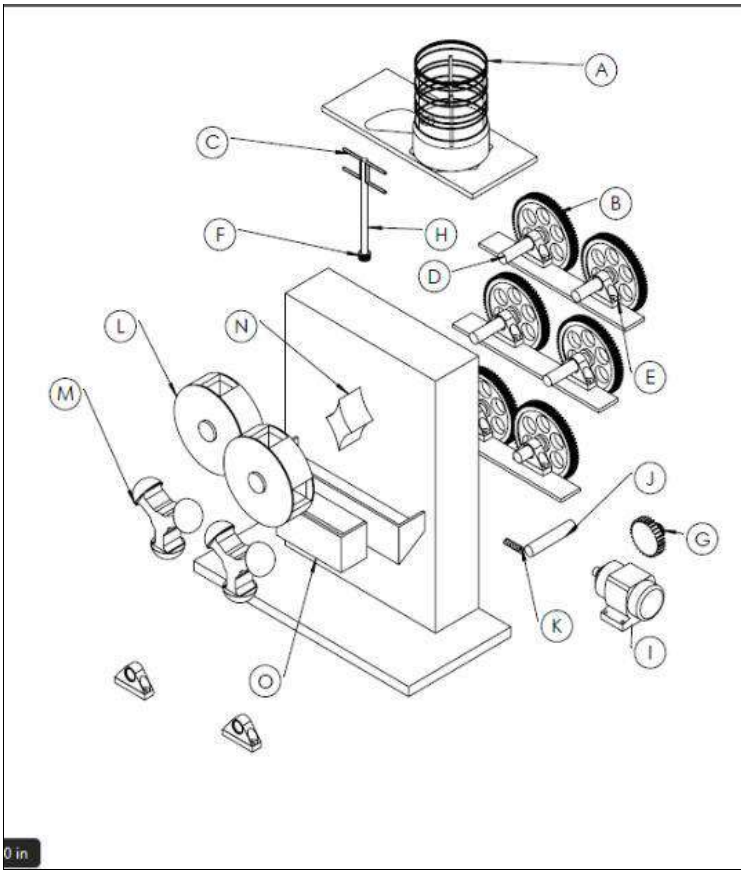
and is been rotated by a shaft attached to one of the six gears. A gear is a toothed wheel that works by engaging another toothed system arranged to change the speed or direction of transmitted motion.



ALPHABET	NAME	NUMBER OF ITEMS
A	HOPPER (FRUIT INLET)	1
B	SPUR GEAR (74 TEETH)	6
C	SPINNER	1
D	SHAFT	6
E	BEARING	9
F	SPUR GEAR (17 TEETH)	1
G	SPUR GEAR (29 TEETH)	1
H	SPINNER SHAFT	1
I	ELECTRIC MOTOR	1
J	TRANSMITI NG SHAFT	1
K	WORM	1
L	COLLECTO R	2
M	ROLLER	2
N	KNIFE	1
O	OUTLET	1

Figure 3: Exploded view of the Juice Extractor Machine

Figure 3 shows seven spur gears G1, G2, G3…G7 mounted on seven different shafts. Gear G1 rotates at 1 revolution in 4 seconds (15rpm).

Where, N_1 = Np = 15 teeth, N_2 = Ng = 45 teeth, N_3 = Ng = 45 teeth, P = 1/3hp = 1.2KW

Tooth pressure angle (Ø) is 200 full depth involutes gear of steel material.
The angular speed of the gear:

$$\omega = \frac{2\pi N}{60} \quad (1)$$

$$\omega = 2 \times 3.142 \times \frac{3}{12} = 1.57 rad/secs$$

$$T_P = \frac{9550P}{N_P} \quad (2)$$

Where: T_P = Pinion Torque (Nm), P= Power, hp (KW); N_P = Pinion speed, rpm.

Since, N_P = 3 revolutions per 12seconds = 15 rpm
Motor power rating (P) = $\frac{1}{3}hp$
But, 1hp = 0.746 KW

$$T_P = 9550 \times \frac{1}{3} \times 0.746$$

T_P = 19.8 Nm

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2.1 Gear Ratio

The desired gear ratio is determined by the designer from the given input speed and expected output speed. It is the ratio of rotational speed of input gear to that of the output gear and can also be referred to as velocity ratio.

$$V_r = \frac{N_g}{N_P} = \frac{D_g}{D_P} \quad (3)$$

Where, N_P= Number of teeth on pinion, N_g = Number of teeth on gear, D_P = pitch diameter of pinion, D_g = Pitch Diameter of gear.

Therefore, $V_r = \frac{N_g}{N_P} = \frac{D_g}{D_P}$
Where, Ng = 45, N_P = 15

$$V_r = \frac{N_g}{N_P} = \frac{D_g}{D_P} \Rightarrow V_r = \frac{45}{15} = 3$$

But

$$T_f = T_i V_r \quad (4)$$

Where, T_f = output torque, T_i = input torque, Vr = Velocity ratio

Since we have Pinion torque (T_P) = 19.8 Nm, Ti = Input torque =?, Vr = Velocity ratio = 3

Hence,
T_f = 19.8 x 3 = 59.4 Nm

2.2 Determination of Shaft Diameter on the Basis of Strength

The basic considerations in the design of shaft strength, are as follows:The maximum shear stress, τmax, of the shaft is calculated using equation (5) from [19] as shown below,

$$\tau_{max} = \frac{16}{\pi d^3} \times \sqrt{(K_m M)^2 \quad + (K_t T)^2} \quad (5)$$

Where, $\tau_{max} = Maximumshearstress$, d = Shaft diameter, $M = BendingmomentT = Torqu$,

$K_m = Numericalcombinedshockandfatiguefactortobeapplied$,
$K_t = Correspondingfactortobeapplied$ $tothecomputedtorques$

Bending moment is insignificant in this case. Kt is equal to 1.0 for rotating shaft with steadily applied loads. Then equation (5) becomes,

$$\tau_{max} = \frac{16}{\pi d^3} \times T \quad (6)$$

Therefore,

$$d = \sqrt[3]{\left\{\frac{16}{\pi \tau_{max}} \times T \quad \right\}} \quad (7)$$

Assuming, $\tau_{max} = 30N/mm^2$, T = 10.2N.m From equation (6),

$$d = \sqrt[3]{\left\{\frac{16}{\pi \times 30} \times 10200 \quad \right\}} = 12mm$$

2.3 Bearing Design

For shafts connected by gears in rotating machines without any impact, the load factor, 'K' assumes any value ranging from 1.1 – 1.5. The desired Life rating 'L' of the bearing is determined from the equation:

$$L = \left(\frac{C}{P}\right)^K \times 10^6 \quad (8)$$

Where, L = Rating of bearing, C= dynamic capacity in Newton, P = equivalent load = 62.98N

K = 3, for ball bearings. Assuming 90% of HTE bearing life rating will reach thirty (30) million revolutions before failure, such that L = 30, Then, equation (8) becomes

$$30 = \frac{C^3}{62.98^3}$$

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$$C^3 = 30 \times 62.98^3$$

Therefore, $C = \sqrt[3]{30 \times 62.98^3}$,

$$C = 195.69N$$

2.4 Evaluation of Juice Extractor Performance

The evaluation of the electric powered juice extractor performance was performed after the fabrication for the purposes of establishing the optimum juice extracting parameters. The extracted parameters include:

2.4.1 Operating Factors

The five levels extraction speed (S) inludes (S_1 = 225, S_2 = 150, S_3 = 95, S_4 = 60 and S_5 = 15rpm) and corresponding three levels feed rate (F) as (F_1 = 2.5, F_2 = 3.0, and F_3 = 3.5 kg/min).

2.4.2. Performance Parameters

The following are the performance parameters juice yield, JY (%), juice extraction efficiency, EF (%) and extraction losses, EL (%).

The gear arrangement aided in obtaining different extraction speeds during the performance test. Using equations 9, 10 and 11 as proposed by [20] and verified in [21]and [22]. The following juice yield, extraction efficiency and extraction loss were calculated as follows:

$$J_Y = \left(\frac{M_{JE}}{M_{JE} + M_{RW}}\right) \times 100 \quad (9)$$

$$E_{eff} = \left(\frac{M_{JE}}{M_{JE} + M_{EW}}\right) \text{x } 100 \quad (10)$$

$$E_L = \left(\frac{M_{FS} - (M_{JE} + M_{RW})}{M_{FS}}\right) \times 100 \quad (11)$$

Where: MJE = Juice extracted mass (kg), MRW = Residual waste/dry pulp mass (kg),

MFS = Feed sample mass (kg), JY = Juice yield (%), Eeff = Efficiency of extraction (%),
EL = Loss of extraction (%).

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.

$$X = \left(\frac{M_{JE} + M_{JC}}{M_{FS}}\right) \quad (12)$$

Where: x = Juice constant of fruit (decimal), MJC = Mass of Juice in the chaff,

The juice constant (x) for orange were determined to be within the range of 0.54 and 0.68, and applied in equation (13) to compute the juice extraction efficiency of the orange as shown below:
For example,

From Table 3 and at feed rate, F1 = M_{FS}= 2.5kg/min

$$J_Y = \left(\frac{M_{JE}}{M_{JE} + M_{RW}}\right) \times 100 \quad (13)$$

2.5 Machine Performance Results

Table 1: Juice Extraction data obtained during the Evaluation of the extractor machine

Operating Factors of the machine		**Extracted Juice mass from the fruit**	**Un- extracted Juice mass from the fruit**	**Fruit pulp mass after extraction**	**Extraction time,**
Speed, S(rpm)	Feed Rate, M_{FS} (kg/min)	M_{JE}(kg)	M_{JC}(kg)	M_{RW}(kg)	T(min)
S_1	F_1	0.79	0.77	0.75	1
	F_2	0.94	0.92	0.95	1
	F_3	1.16	1.12	1.03	1
S_2	F_1	0.82	0.75	0.75	1
	F_2	0.95	0.91	0.96	1
	F_3	1.18	1.13	1	1
S_3	F_1	0.89	0.71	0.8	1
	F_2	1.2	0.72	0.97	1
	F_3	1.34	1.04	1.03	1
S_4	F_1	0.79	0.56	0.69	1
	F_2	1.1	0.59	0.83	1
	F_3	1.29	0.89	0.89	1
S_5	F_1	0.81	0.55	0.68	1
	F_2	1.14	0.59	0.82	1
	F_3	1.32	0.58	0.87	1

S_1 = 225rpm F_1 = 2.5kg/min
S_2 = 150rpm F_2 = 3.0kg/min
S_3 = 95rpm F_3 = 3.5kg/min
S_4 = 60rpm
S_5 = 15rpm

Table 2: Effect of some Operating Factors on the performance of Juice Extraction machine

Operating Speed(rpm)	**Feed rate (kg/min)**	**Juice Yield, J_Y (%)**	**Juice Extraction Efficiency, E_F (%)**	**Juice Extraction Losses, E_L (%)**
S_1	F_1	51.29	50.64	49.36
	F_2	49.74	50.54	49.46
	F_3	52.97	50.91	49.09
S_2	F_1	52.23	52.23	47.77
	F_2	49.73	51.08	48.92
	F_3	54.13	51.08	48.92
S_3	F_1	52.66	55.63	44.37
	F_2	55.3	62.5	37.5
	F_3	55.54	56.3	43.7
S_4	F_1	53.38	58.52	41.48
	F_2	56.99	65.13	34.87
	F_3	59.17	59.16	40.84
S_5	F_1	54.36	59.56	40.44
	F_2	58.16	65.86	34.14
	F_3	60.27	69.46	30.54

S_1 = 225rpm F_1 = 2.5kg/min
S_2= 150rpm F_2 = 3.0kg/min
S_3 = 95rpm F_3 = 3.5kg/min
S_4 = 60rpm
S_5 = 15rpm

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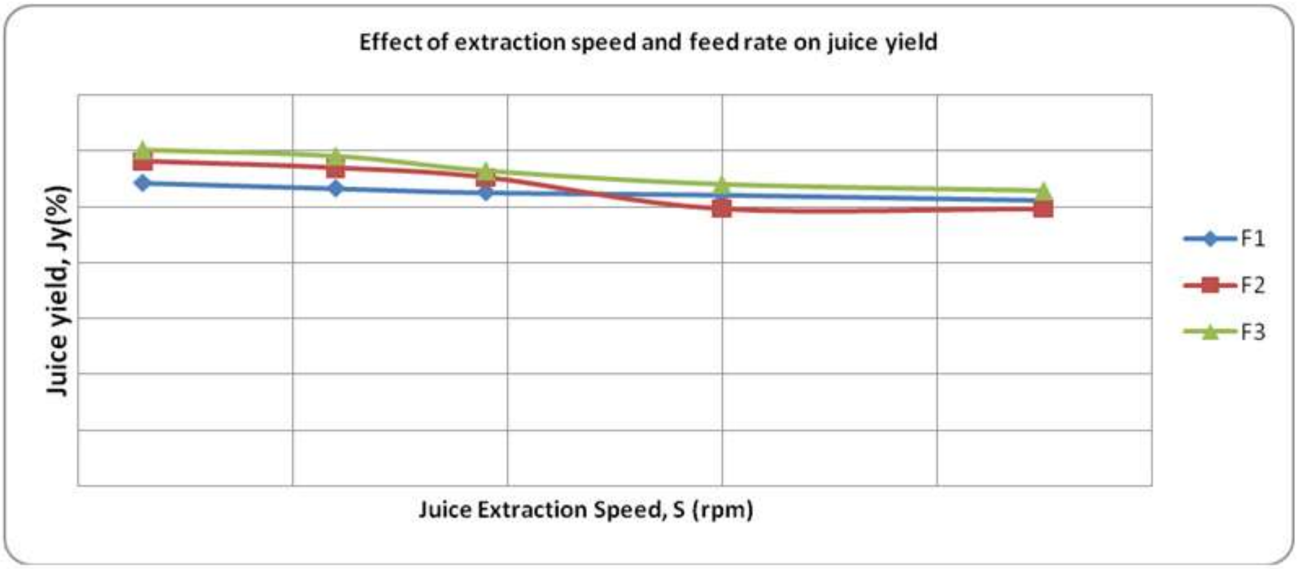

Figure 4: Effect of Extraction speed and Feed rate on juice yield

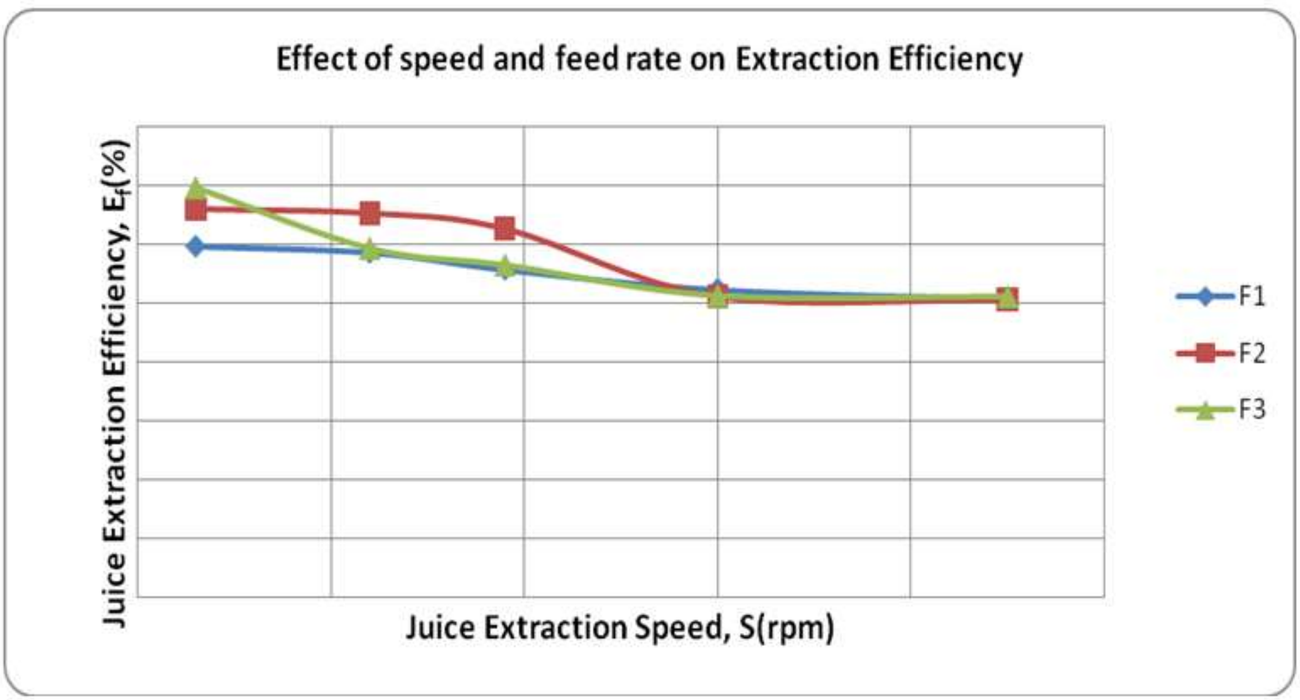

Figure 5: Effect of juice extraction speed and feed rate on extraction efficiency

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Figure 6: Effect of speed and feed rate on Extraction Losses

III. RESULTS AND DISCUSSION

The Tables 1 and 2 with Figures 4, 5 and 6. Explain the evaluation test results carried out on the juice extraction machine.

3.1 Juice Yield

The result in table 1 illustrates the orange juice extractor optimum feed rate as F_3 (3.5 kg/min). More juice yield was obtained from orange fruits because there are sufficiently juicy in nature. Consequently, more juice yield was extracted at each operating speed of the fabricated electric powered juice extractor than was obtained from manually operated extractor.
Broadly, the overall juice yield of these machine decreases as the juice extractor machine operating speed increases and vice-versa (Figure 4). As the speed of operation increases, there is a significant reduction in juice extraction from the oranges. The losses may be due to vibrational high operating speeds which causes splashing of juice around the walls of the xtractor, thus reducing its yield. Hence, to obtain high juice yield a controlled speed should be sustained when operating the machine for an optimal juice extraction.

3.2 Extraction Effficiency

Figure 5 showed the orange juice extraction efficiency of the machine. The extraction efficiency of machine rose to a maximum value of 70% at optimum operating speed of 15rpm and optimum feed rate F_3 (3.5 kg/min), and then declines at speeds beyond 15rpm. Fruits were not completely squeezed at high speeds which thn caused the reduction in the amount of juice extracts compared to when it was tested at a slow and steady speeds. Thus, the performance evaluation tests proved the optimum extraction efficiency of the electric powered juice extractor machine to relies on the fruit nature and the extraction speed of the machine to produce the juice extracts . The rotary balls have a major responsibility to play since the sizes of orange fruit that passes down to the collectors where the fruit juice were finally extracted is considered as prime. The roughness rises as speed increases while there is a decline in extraction time as the extraction speed rises.

IV. CONCLUSION

The juice extraction machine was successfully designed, neatly constructed, assembled judiciously and tested. The optimum operating speed of the juice extraction machine was found to be 15rpm, while the optimum feed was found to be F_1 (2.5 kg/min). The average juice extraction efficiency at optimum speed (S) and feed (F) was 64%; juice yield at optimum S and F was 60%; juice extraction losses was 35% at optimum S and F. The juice extractor machine cost about N125, 000, which makes it affordable for both small and medium-scale farmers in the country.

Conflicts of Interest

The authors wish to declare no conflict of interest.

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