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Development of a Manually Operated Tomato Juice Extractor

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Abstract**-**Post-harvest losses of fruits and vegetables are higher in developing countries than in well developed countries. Large quantities of tomatoes are wasted in Nigeria due to lack of good preservation techniques. Tomato fruit (*Lycopersicum esculentum*) provide basic nutrition, essential, mineral elements and vitamins necessary for well-being, preventing chronic diseases and other health benefit. Processing tomato into the form that can easily be stored, preserved, packaged, transported or consumed is crucial to having the product all the year round. The objective of this project is to design, fabricate and test a manually operated tomato juice extractor, as well as to evaluate the performance in terms of juice yield, extraction efficiency and extraction loss of tomato fruit. Tomato juice extractor was designed, fabricated and tested having the following major components: hopper, extraction chamber, juice outlet, sieve, frame, gear compartment, handle, shaft, juice collector and the top cover. The feeding compartment otherwise known as the hopper with a volume capacity of 4.58×10^{-3} m^3 was designed and fabricated. The extraction chamber consists of a perforated aluminum plate used as a sieve. The extraction is actually achieved by the action of the shaft blades in pressing the tomato against the roughened/abrasive internal surface of the perforated cylindrical sieve. The juice extracted drops in the juice collector and the mushy part can be removed manually by detaching the hopper and removing it with hand. The juice collector is almost cubical in shape and it is made of stainless steel. The machine was tested using freshly harvested tomato fruits the results obtained showed the average extraction efficiency, extraction loss and juice yield as 78.95%, 3% and is 77% respectively. The extraction capacity of the machine is 0.6 kg/min. The machine which operates manually was found to be easy to operate, repair and maintain and this makes it suitable for people living in rural communities and small scale farmers.

Keywords- *Fruits, Juice Extraction, Manually-Operated, Performance Evaluation*

I. Introduction

Fruits are seasonal and therefore are not available in sufficient quantities throughout the year because it is difficult to store them in their natural form. The major problem is the high perishing rate of fresh fruits especially in the Sub-Saharan region due to high moisture content which aid chemical deterioration [1, 2]. A study carried out on fruits indicated that the losses were up to 30 % during the rainy season [3]**.** This problem leads to scarcity as well as high cost of fresh fruits during the off-season. This has made it necessary for continuous research in ways to preservation of fruits. Extraction of the liquid content (juice) has been found to be one of the best methods for fruits preservation. Juice extraction is the process by which the liquid portion of the fruit is separated from the solid portion by means of an extractor. The quality of the juice depends on the variety and maturity of the fresh fruit. Some fruit juices can take months or even years before they expire depending on how well they were preserved and packaged [4].In many areas, they are plentiful but seasonal, thus expensive.

Fruit juice is a ready source of vitamins, fiber and mineral salt for human consumption due to its use as medicine, food and appetites [5].Fruit juice extraction involves the process of crushing, squeezing and pressing of whole fruit in order to obtain the juice and reduce the bulkiness of the fruit to liquid and pulp. According to Abulude *et al* [4], the various processes involved in fruit processing include: sorting, washing, pressing, slicing, crushing and extraction, addition of additives, homogenization, pasteurization (heat treatment), packaging and storage. 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. Fruit juice is originally produced as a result of surplus production of fruits, but it is obtained from processing specially grown species for that purpose. Juice obtained from citrus fruits like orange (*Citrus sinensis*), tangerine (*citrus reticulata*), grape (*Citrus paradisi*), lemon (*Citrus Limon*), and lime (*Citrus aurantifolia*) dominate the market. Other main sources of juice are pineapple (*Ananas comosus*), mango (*Mangifera indica*), water melon (*Citrullus lanatus*), pineapple (*Ananas comosus*), Cashew (*Anacardium occidentale*) and Tomato (*Solanum lycopersicum*) [6].

Tomato is indigenous to the Peru and Ecuador region in South America and it probably evolved from *Lycopersicon esculentum*, the cherry form [7]. It belongs to the family *solanaceae* and may interchangeably be referred to as *solanium lycopersium* or *lycopersicon esculentum* [8]. However, it was domesticated and first cultivated in Central America by early Indian civilizations of Mexico. The Spanish explorers introduced tomato into Spain and it was later taken to Morocco, Turkey and Italy. In Italy and France, it was termed “love apple”. It was widely believed that the tomato was poisonous and its use as a food crop was only accepted in the 18th century. Tomato which is arguably a fruit due to its high water contents, fiber contents and seeds typical of other fruits like water melon, guava, and grape. Tomatoes come in different varieties that vary in shape, size and colour. It is an edible, typical red, fruit as well as the plant (*Solanum lycopersium*) which bears it [9].

In Nigeria, tomato is regarded as the most important vegetable after onions and pepper [10]. It is an important condiment in most diets and a very cheap source of vitamins. It also contains a large quantity of water, calcium and Niacin all of which are of great importance in the metabolic activities of man. Many varieties of tomatoes grow in Nigeria, all of which may be rich in various macro and micro-nutrients. Tomato is a good source of vitamins K, A, B, C and minerals (potassium, chromium, coumaric acid and chlorogenic acid) that are very good for body and protect the body against diseases [11]. One of the most well-known tomato eating benefit is its' Lycopene content. Lycopene is a vital anti-oxidant that helps in the fight against cancerous cell formation as well as other kinds of health complications and diseases. Free radicals in the body can be flushed out with high levels of Lycopene, and the tomato is so amply loaded with this vital anti-oxidant that it actually derives its rich redness from the nutrient.

Nigeria, Africa's largest country is Sub-Saharan Africa's biggest producer of tomatoes, produces up to 1.5 million tons of tomatoes every year. Making it the 14^{th} largest producer of tomatoes in the world, according the Nigeria Ministry of Agriculture. However, despite Nigeria's strong position in tomato production, it still spends up to $500 million every year to import tomato products (especially purees, pastes and canned tomatoes), making Nigeria one of the biggest importers of tomato paste in the world [12]. A large percentage of tomatoes produced in Nigeria is wasted and one of the measures of solving it is by juice extraction.

Tomato juice is processed from ripe tomatoes and serves as beverage drink around the world. The old method of extracting juice from fruit involved macerating fruit with hand or peeling, slicing, blending and pressing the fruit. This is energy sapping and time consuming method, it also yield low quality and unhygienic fruit. The old method 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.

An extractor from locally available materials is therefore necessary to effectively and efficiently extract juice from various fruit at a low cost so as to encourage fruit juice consumption for a healthy life. It is also desirable for longer preservation of the fruit. The objective of this work is to design, fabricate and test a manually operated tomato juice extractor, as well as to evaluate the performance in terms of juice yield, extraction efficiency and extraction loss of tomato fruit.

II. MATERIALS AND METHOD

The following were the main consideration in the design of the manually operated tomato juice extractor: (a) the machine should be able to extract juice from the tomato fruits efficiently and should be simple as possible to ensure ease of operation (b) In the selection of materials for construction, adequate care was taken not to use materials that can contaminate the tomato fruits and also materials that cannot corrode easily (c) The product surface must be free from crevices which can harbor bacteria (d) It should be simple to ensure ease of operation and maintainability.

A. Machine Description and Working Principles

Tomato juice extractor as shown in figure 1 has the following components which are feeding hopper, top cover, driving gear, driven gear, juice sieve, juice collector, handle, shaft and main frame. A machine was designed for small scale tomato juice extraction. In operation, the tomatoes are feed into the hopper and the rotating shaft which has spikes in rotary motion aids in pressing the tomatoes, it is also the duty of the rotating shaft to transport the tomato from the point of input to the to the sieve where crushing, pressing and squeezing takes place in order to extract the juice. In operation, the tomato is feed into the hopper and the rotatory motion of the shaft blades conveys the tomato, meshes it and presses the tomatoes against a sieve on the inside. The extraction chamber consists of a perforated aluminum plate used as a sieve. The perforated aluminum plate is essentially a halved cylindrical drum on which series of perforated holes were drilled in an orderly manner. The perforations are roughened in the internal surface of the drum to form an abrasive surface for tearing the fruit mesocarp and enhance the flow of juice. In operation, as the shaft rotates at its required speed, the shaft blades press the tomato fruits against the roughened/abrasive sieve surface in such a way that the tomato is softened. The extraction is actually achieved by the action of the shaft blades in pressing the tomato against the roughened/abrasive internal surface of the perforated cylindrical sieve. The juice extracted drops is filtered through the juice sieve into juice collector and the mushy part can be removed manually by detaching the hopper and removing it with hand.

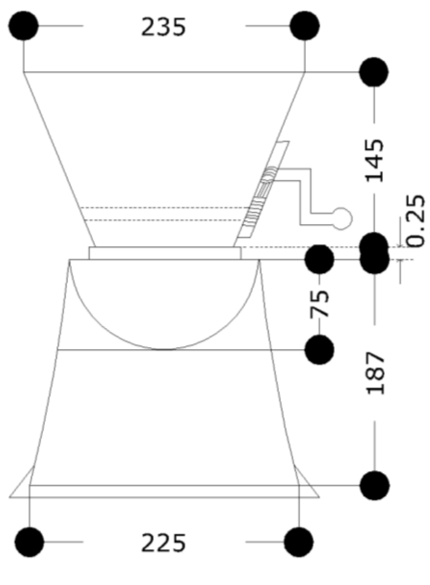

Figure 1. Front view of Tomato Juice extractor

B. *Design of Component Parts*

In designing tomato juice extractor, the following were put into consideration, easy to operate, affordability, ease of maintenance, portability, aesthetic value and production of high nutritional value of juice. The extraction chamber and juice collector is desired to be made of stainless steel to ensure quality and safety of juice and to design the extraction chamber to accommodate the required quantity of tomato fruit.

1) *Design for Hopper*

The hopper of volume of $4.58x10^{-3}m^3$ was designed to accommodate 120 pieces of tomato. A 2.5 mm thick stainless steel plate was used in the construction. The hopper has a shape of a pyramidal frustum (special case of prismatoid) for a right pyramidal frustum. Then the volume of a pyramidal frustum is calculated according to Harris and stocker [13] as follows:

$$V = \frac{1}{3} h \left(A_1 + A_2 + \sqrt{A_1 A_2} \right) \quad (1)$$

Where A_1 is the area of the top of square hopper (0.235 x 0.235 m), A_2 is the area of the bottom of the square hopper (0.115 x 0.115 m) and h is the height of the hopper (0.145 m)

Therefore number of tomatoes that can be feed into hopper at once ranges between 120-150 tomatoes.

2) *Spur Gear Analysis*

Spur gears are cogged wheels whose cogs or teeth project radially and stand parallel to the axis. The main formular for dimensions of standard spur gears are given in Machinery's hand book and Mechanical Engineers handbook [14, 15]. The results of geometrical parameter's calculations for 49 (big gear) and 14 (small gear) teeth gears are presented in table 1.

TABLE I. CALCULATION FOR BIG AND SMALL GEAR GEOMETRY

Description	Formula	Big gear	Small gear
Diametral Pitch (DP)	$p = N / D$	42.9	44.4
Pitch Diameter (PD)	$PD = N / P$	1.142	0.315
Pitch Circle	$PD = (DP_1 + DP) / 2$		
Addendum (A)	$A = 1 / P$	0.0233	0.0225
Dedendum (B)	$B = 1.25 / P$	0.0270	0.0261
Outside Diameter (OD)	$OD = (N - 2) / P$	1.19	0.36
Root Diameter (RD)	$RD = (N - 2.5) / P$	1.10	0.27
Base circle (BC)	$BC = D \times COS\,\phi$	1.14	0.32
Circular Pitch (CP)	$CP = 3.1416 / DP$	0.0732	0.0708
Circular Thickness (T)	$T = 3.1416 / 2DP$	0.0366	0.0354
Whole Depth	$WD = 2.157 / DP$	0.0563	0.0486
Centre Distance	$CD = (PD_1 + PD_2) / 2$		
Gear Ratio	$GR = N_G / N_d$	3.5	1

NB: Centre Distance: is given as 0.73

3) *Torque in Gear Drives*

Torque is a measure of the turning or twisting force that acts on axles, gears and shafts. Torque is proportional to the gear ratio. This means that in a gear drive system with 3.5:1 ratio, the torque transmitted from the drive gear to the driven gear is multiplied 3.5 times.

C. *Evaluation of the Machine Design*

The frame is made of a 30 × 30 × 3mm angle iron which supports the entire weight of the machine. Iron was used in constructing the stand. This provides enough rigidity and strength to carry the weight of the component parts and to withstand the vibrations emanating from the machine's operation. The hopper has the shape of a frustum of a pyramidal truncated at the top, with top and bottom having rectangular forms. The bottom was designed to accommodate the largest specie of tomato fruit. The spiked shaft is made of iron rod 120 mm in length and a thickness of 15 mm. The spikes on the shaft are spaced to ensure easy rotation with each space being 10mm. The length of the spike is 55mm. The spikes are all welded to the main shaft which helps in pressing of the tomato fruits. The juice collector is almost cubical in shape and it is made of stainless steel. The reason for the use of stainless steel is for the juice not to get contaminated. More so, Stainless steel does not rust over a long period of time despite the usage condition. A handle was designed to be 100mm in length while the diameter was designed to be 8 mm and is attached to ensure ease of pulling out and insertion into the base region of the extractor.

D. *Performance Evaluation*

Testing procedure: Fresh tomatoes were obtained from Waso market in Ogbomoso. The best were sorted and washed. 1.6 kg of tomatoes were fed into the hopper, the shaft which has a spike, set in rotary motion was used to press tomatoes against rough surface to extract juice. Both the juice extracted and the residual were collected and weighed separately. From values obtained, juice yield, extraction efficiency and extraction loss were determined using Tressler and Joslyn [16] equation as:

$$J_Y = \frac{100 W_{JE}}{W_{JE} + W_{RW}} \% \quad (2)$$

$$J_E = \frac{100 W_{JE}}{x W_{FS}} \% \quad (3)$$

$$E_L = \frac{100 \left[W_{FS} - \left(W_{JE} + W_{RW} \right) \right]}{W_{FS}} \quad (4)$$

$$Extaction\ capacity = \frac{weight\ of\ juice\ (kg)}{time\ taken\ (min)} \quad (5)$$

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 tomato in decimal. Each test was carried out in triplicates.

III. RESULTS AND DISCUSSIONS

The average juice yield, extraction efficiency and juice loss were 77%, 78.15% and 3%, respectively. The extraction capacity of the machine is 0.6 kg/min. The average revolution of the manual extractor is 90rev/min. Volume of the hopper as calculated earlier is $4.58 \times 10^{-3}m^{-3}$; this can contain 120 pieces of tomatoes at a time. In 1 minute 0.6 kg tomato juice was extracted from 60 pieces of tomatoes. Hence, it takes an hour to produce 36 kg of tomato juice by the manually operated tomato juice extractor. Weight of juice that can contain the juice collector at once is 1.6 kg. These values compared favourably with what other researchers have found out. The results of the test showed that the machine performed satisfactorily but there is still room for improvement.

IV. CONCLUSION

A small scale tomatoes juice extractor was designed, constructed and tested. This machine was designed and constructed to extract juice from tomato fruits in order to reduce the usual wastage during peak harvest on most plantations in Nigeria and subsequently to complete favorably with the imported tomato paste. The extractor was portable enough for local production, operation, repair and maintenance. Results of the tests revealed a juice yield of 77%, with an extraction efficiency of 78.15%. The extraction capacity is 0.6 kg/min at 90 rev/min and the cost of production is N33, 000.00. This machine can be used for small scale tomato juice extraction in rural and urban communities.

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