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DESIGN AND CONSTRUCTION OF AN ELECTRICALLY POWERED TOMATO SLICING MACHINE

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Abstract
This study shows a Proto-Type Construction of an Electrically Powered Tomato Slicing Machine (Design of the Proto-Type). The feeding unit of the tomato slicer was made from a pyramid shaped plates in which tomatoes to be sliced dropped by gravity and slight agitation of the machine into the slicing unit. The feeding unit has the plate size of 100mm x 50mm. the average diameter of UC-82b variety of tomato is 45.23mm measured. The feeding unit can take up to 20 tomatoes therefore the capacity of the feeding unit is thus 20 x 45.23 = 904.6g. The tomato slicer is operated by switching on the electric motor which drives the stainless blades inside the slicing unit. The blades move in rotational order depending on clockwise and anticlockwise rotation of the electric motor. A certain quantity of matured tomato fruits of UC-82B variety was purchased from Mando Market in Igabi Local Government Area of Kaduna State, Nigeria. The results show that the machine output capacity, slicing efficiency and percentage damage were 85kg/hr, 65% and 25% respectively. The percentage damage ($Dp = \frac{Wd}{WT} x\ 100\%$) *which can be due to mechanical errors (wear & tear). The output capacity* ($Co = \frac{WT}{T}$) *and the slicing efficiency* ($\eta = \frac{Ws-Wd}{Ws} x\ 100\%$) *of the slicer were determined using the relations. The study concluded that an electrically powered tomato slicer was constructed and tested and found to be efficient with the values obtained as (Output capacity is 85kg/h, the efficiency is 65% and the percentage damage is 25%). Based on the conclusion the study recommended that knife carriage should be redesigned to be more rigid and a motor with much slower speed than the one used is equally suggested, then the feeding unit should be increased to accommodate more tomatoes at a time.*

Key Words: *Design, Construction, Performance, Tomato, Slicing machine*

Introduction

Tomato (*Selenium lycopersicum*) is an edible fruit with high nutritive values. Tomato fruit contains per 100 g, 94.6 g water, 0.5 g protein, 0.1g fat, 0.4 g ash, 223 mg potassium, 22mg phosphorus, 0.04 mg thiamine, 0.01 mg riboflavin, 0.6 mg niacin, 349 carotene, 507 lycopene, 22mg vitamin C and the energy value is 61 Kj. It is one of the most popular and widely consumed vegetable crops all over the world (Al-Amri, 2013). Nigeria is the second largest producer of tomato in Africa where a total area of one million hectares is used for tomato cultivation per annum (Bodunde *et al.,* 2013). Tomato fruit is highly susceptible to spoilage owing to its high moisture content of about 95% w.b. which provides favourable condition for micro-organisms. Other factors that cause rapid deterioration of tomato were ascribed to rough handling, poor processing and preservation techniques. In Nigeria, Opadokun (2017) submitted that 21% of tomato fruits harvested are lost to rot in the field and additional 20% to poor storage system, transportation and marketing. The estimated total loss of tomato in Nigeria due to various constraints is about 60% (Babalola *et al.,* 2010).

Tomato which is referred to as plant (*Selenium lycopersicum*) or the edible is very nutritionally essential in body as a fruit or vegetable. It is believed to benefit the heart, among other organs. It contains carotene lycopene, one of the most powerful natural antioxidants. In some studies, lycopene especially in cooked tomatoes has been found to be helpful to various agricultural farmers.

Presently in Nigeria, slicing of tomato for the purpose of sun drying is a common practice for its preservation. The traditional method of slicing with knives is one of the widely adopted methods. This method is time-consuming, full of drudgery, unhygienic and consequently hazardous. To improve the processing method and enhance its hygienic level, there is need for electric powered slicing process. Researchers have developed slicers for many other crops, but tomato electric power slicers are still rare. Raji and Igbeka (1994) designed, fabricated and tested pedal operated chipping and slicing machines for cassava, yam and potato. It has a rectangular hard type of plastic container with grooves marks along its length into which several shapes of cassava, potatoes, and yam can be sliced. The grooves were designed to a predetermined depth through which the rotary knives cut to the designed width or thickness. The throughput capacity of the equipment was 377 kg/hr.

Tomato (*selenium lycopersicum*) is an important fruit vegetable consumed all over the world. The consumption of tomatoes in recent time has increased due to the associated benefits of some *phytochemicals* including carotenoids. Other notable component of tomatoes is vitamin C. Depending on variety and growing conditions, the vitamin C content of tomatoes may vary between 39-263 mg/100 g. For instance, tomatoes grown on organic substrates were found to contain significantly more calcium and vitamin C than tomatoes grown on hydroponic media. Tomatoes may be eaten either raw or cooked. Being a climacteric and perishable vegetable, tomatoes have a very short lifespan, usually 2-3 weeks (Sibomana *et al,* 2015). Hence, tomato fruits must be properly handled after harvest in order to maintain quality and enhance consumer appeal during sale. The quality of tomato is determined by appearance, firmness, flavour and the nutritive value. These quality parameters are affected by several factors including, variety, agronomic practices, method of harvesting, time of harvesting, postharvest handling techniques, packaging materials and storage conditions. Packaging generally helps to protect and retain the quality of fresh horticultural produce and reduces damage during transport. Sammi and Masud (2009), reported that packaging can significantly reduce fruit weight loss of tomatoes when sealed in plastic films and can extend the marketable life. Since consumers are interested in produce with good quality and long shelf life, it is important to package fresh commodities in materials that will meet these requirements. In general, packaging material will not only hold the food substance, but will also protect it from contamination. They also extend the marketable life of the product (Sammi, and Masud, 2009). However, the type or quality of packaging material may also influence the product quality. For example, tomato packed in polyethylene bags showed significantly lower weight loss (approx. 10%) compared to tomato fruits packed in grease free papers, which showed approximately 20% weight loss after 28 days of storage at ambient temperature of 32 ± 2°C (Shahnawaz et *al.*, 2012). Commercially, different packaging materials are used in the wholesale and retail market for the sale of fresh produce such as tomatoes. As stated above, the properties of these packaging materials may influence the product quality.

Fresh produce quality generally decreases after harvest. The decrease in quality could be attributed to the respiratory activities that continue after harvest. Since there is a growing demand for fresh fruits and vegetables, due to the increased consumption of these commodities, many industries are employing different methods to improve the quality of fresh produce. Several methods including temperature control, use of efficient packaging materials, product pre-treatment and the use of fruits with initial good quality are being used to maintain or reduce the postharvest losses of fresh commodities. Tomato is an important commodity both for the fresh and processing markets (Fagundes *et al.*, 2015). The shelf life of tomatoes is relatively short (Hoeberichts *et al.,* 2002) due to different postharvest physiological, physical and chemical changes that occurs during storage (Fagundes *et al*., 2015). These changes are triggered by the production of ripening hormone called ethylene (Carrari and Fernie, 2006). Hence, postharvest handling of tomatoes is essentially targeted at reducing the rate of respiration and the concomitant control of the ethylene production (Martínez-Romero *et al.,* 2007). Many strategies and techniques are being investigated to reduce these changes in fruits and to enhance the keeping quality. The following section discusses the nutritional value, utilization, quality and the factors that can influence the quality of tomatoes.

Manual cutting and slicing of vegetables such as tomato has proved to be very time consuming and is prone to the risk of contamination of the food leading to high rates of foodborne diseases. The existing tomatoes cutters and slicers have been designed based on different criterion. The technology of slicing and cutting of vegetables has dated back to around the

1970s (Jiang, 2013). Traditional methods of cutting and slicing tomato have been used since a long time back. People cut and or slice their vegetables using knives. This method is regarded the cheapest one as it does not require sophisticated mechanisms to carry out. Complications arises when evaluating the accidents associated with this method, people tend to accidentally cut themselves whilst trying to make suitable cuts and slices.

After careful study of indigenous way of slicing tomatoes, it was observed that it involves a lot of physical labor and material wastage. Therefore, to improve the processing method and enhance its hygienic level, there is a need to design, fabricate and construct electric powered tomato slicing machine which uses electric motor, belt and pulley for its tomato slicing operation. The objective of the study is to design, construct and evaluate the performance of a proto-type tomato slicing machine.

Materials and Methods

Cost Estimate and Materials Specification

Table 1 Cost Estimate and Materials Specification

S/N	Materials	Specification	Quantity	Unit cost (₦)	Total cost (₦)
1.	Angular iron	6.4mm	2	8,300	16,600.00
2.	Stainless steal	1.4mm	Half sheet	3,000	1,500.00
3.	Bearing		1	7,000	7,000.00
4.	Turner operator		1	4,000	4,000.00
5.	Electrode		Half pack	2,000	1,000.00
6.	Labour				
7.	Miscellaneous				10,000
8.	Transportation				3,000
	Total				43,100.00

Design of Machine Elements and Parameter

Capacity of the Feeding Unit

The feeding unit of the tomato slicer was made from a pyramid shaped plates in which tomatoes to be sliced dropped by gravity and slight agitation of the machine into the slicing unit. The feeding unit has the plate size of 100mm x 50mm. the average diameter of UC-82b variety of tomato is 45.23mm measured. The feeding unit can take up to 20 tomatoes therefore the capacity of the feeding unit is thus 20 x 45.23 = 904.6g.

Shaft Design

The machine shaft was designed to move a nut that carries the blade. ACME (not threaded) shaft of 15mm outer diameter made from mild steel was selected based on rigidity to carry the cutting blades using that basic dimension for Acme shaft as given by Khurmi and Gupta (2005). The shaft has the following parameter; d_o = 15mm, d_c = 10.2mm and Ac = 110mm^2

Where;

d_o = Outer diameter of the shaft (mm)

d_c = Minor of core diameter of the shaft (mm)

A_c = Area of core (mm^2)

Relation for the power of electric motor driving a power shaft is given as:

Pm = T x w ………………..……1.

(Khurmi and Gupta, 2005)

Where;
pm = Power of the motor (w)
T = Torque required to operate the shaft (Nm)
w= Angular speed (rad/s)
But Torque (T) is given as
$T = p \times {}^{d}/_{2}$ ……………………….2
Where;
p = Tangential force at the circumference of the shaft (N)
d = Diameter of shaft (mm)
p is given as:

$$p = w \tan(\alpha + \emptyset) = w\left(\frac{\tan\alpha + \tan\emptyset}{1 - \tan\alpha\tan\emptyset}\right) \quad \ldots 3$$

Where ;
w= load to be lifted by the shaft (N)
α = coefficient of friction between shaft and nut
Ø = angle of friction (coefficient of friction as η = tan Ø = 0 .15) (Khurmi and Gupta, 2005).

Determination of load to be lifted by the shaft (w)

Mass of carriage = 0 .60kg (measured)
Therefore, force due to carriage = 0.60kg x 9.8m/s^2 = 5.89N
Mass of each blade = 0. 20kg (measured)
Therefore force due to the three blade is 3 x 0. 20kg x 9.8m/s^2 = 5. 89 N
Mass of a nut = 0 .002 kg (measured)
Therefore force due for the 2 nuts =
2 x 0 . 002kg x 9.81m/s^2 = 0.039N

Cutting resistance of tomato fruits

Maimunatu (2005) gave maximum shearing force resistance of tomato fruits as 0.4750N/mm,
Measured average major diameter of UC – 82B variety of tomato is = 45.23mm
The shearing resistance of tomato is therefore 0.4750 x 45.23 = 21.48N
Also the slicer is designed to cut through one (1) tomato at a time, therefore, force resistance of tomato = 1 x 21.48 = 21.48N
w = 5.89 + 5.89 + 0.039 + 21.48
w = 33. 29N
Equation for coefficient of friction α
$\tan\alpha = {}^{p}/_{\pi d}$……………………………4
But the diameter of shaft can be determine from equation 3.1.2.5 as given by (Khurmi and Gupta, 2005).
As:
$d = d_o - {}^{P}/_{2}$
Therefore;
d = 15 – ½
d = 7.5mm
Hence, from equation ………………5

$$\tan\alpha = \frac{1}{3.142 \times 7.5}$$

tan α = 0.0429

Electric Motor Power Estimation

From equation ……………………3

$$p = 33.29\left(\frac{0.429 + 0.15}{1 - \tan(0.0429) \times \tan(0.15)}\right)$$

p = 6.47N
Hence Torque from Equation …….6

$$T = 6.47 \times \frac{7.5}{2}$$

T = 24.26 Nmm or 0.02426Nm

$$W = \frac{2\pi N}{60} \quad \text{…………… equation 7}$$

If we Assume the tomato will be cut at speed of (v) = 1000Nmm

$$N = \frac{V}{p} = \frac{1000}{1} = 1000\text{rpm}$$

Therefore;

$$w = \frac{2 \times 3.142 \times 1000}{60}$$

w = 104.73rad/s
From equation ………1 (Khurmi and Gupta, 2005) is given as;
Pm = 0.02426 x 104.73
Pm = 2.5407498w or 0.00254kw
But the capacity of the prime mover required can be obtained from equation 7.

As given by (Mohammed and Hassan, 2012).

$$Pr = \frac{pm}{\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where:

Pr = capacity of prime mover required (kw)

η = 0.85 assumed drive efficiency

Therefore;

$$Pr = \frac{0.00254}{0.85}$$

Pr = 0.00299kw

Components of the Slicing Machine: The tomato slicing machine consists of the following components: hopper, slicing chamber, and shaft, slicing blade, pulleys, frame, motor and bearing.

Description of the Components in the Construction Proto-type

Hopper: This is the feeding units, which is triangular in shape where it is temporarily stored before and during processing. The hopper, which is constructed using stainless steel of 2mm thickness and was place at an inclined angle (slide) so as to allow specific sizes of slicing.

Slicing Chamber: This is the main slicing chamber made up of stainless steel of 1.6mm thickness. It is round in shape and it comprises of slicing blades inside. It has a height of 26cm and width of 6cm.

Power Screw (Shaft): It is made up of mild steel bar with the length of 40cm and thickness of 25mm. It is coupled with the slicing blade and with pulley at the other end for the transmission of power from the motor to the slicing blade for slicing the material.

Slicing blade: This is made up of stainless steel. They are three in number and they are rectangular in shape. They have length of 10mm and width of 3mm.

Pulley: This is a kind of wheel drive that will be attached to the shaft of the slicer in connection to the electric motor through the belt.

Electric Motor: This is the main power source for the operation, and 1.5hp is used for proper operation.

Machine Description and Working Principle

Machine Description: The tomato slicer comprises of different units, these include: Tomato feeding unit, slicing unit, collection unit, power unit and frame. The machine is mainly from mild steel and stainless steel. It is rectangular with the feeding unit pyramidal in shape, all these are made up of mild steel plate and the slicing unit which is made of round stainless plate were welded to form a vertical column to which tomatoes to be sliced are fed into the machine. The feeding unit can take 18-20 tomatoes at a time. Tomato fruits drop by gravity onto the slicing unit from the feeding unit and through to the collection unit. The slicing unit consists of 3 blades arranged at equal distance from each other attached to the shaft that allow for rotational movement, these blades are made of stainless steel. The power shaft is 12mm outer diameter, 1mm pitch and 220mm long. It transfers rotary motion of the prime mover unto the slicing rotary motion of the blades. The power shaft is fixed horizontally at one end directly to the prime mover and at the other end to a ball bearing. Blade carriage is attached to the power shaft by a nut. The nut carries the carriage together with the blades in rotational movement. The collection unit made from stainless sheet metal plate is triangular in shape, it has a total volume of 904.6mm^3. The power unit comprises of an electric motor of 1hp and 1000rpm which can rotate in both clockwise and anti-clockwise direction under the control of a switch. The power unit and all other machine components were assembled on the tool frame for them to function as an entity.

Working Principle: The tomato slicer is operated by switching on the electric motor which drives the stainless blades inside the slicing unit. The blades move in rotational order depending on clockwise and anticlockwise rotation of the electric motor. As tomato fruits are fed into the vertical columns in the feeding unit, the fruits drop by gravity and slight agitation of the machine onto the slicing unit and other fruits queue up in the vertical columns, the tomato fruit is cut by the blade with a rotational force or tongue, the process is continuous as the sliced tomato dropped to the collecting unit. The next sets of tomato fruits in the feeding unit drop onto the slicing unit and the process is repeated.

Result and Discussion

Performance Evaluation of the Machine

Tomato Fruits Samples: A certain quantity of ripe tomato fruits of UC-82B variety was purchased from Mando Market in Igabi Local Government Area of Kaduna State, Nigeria. The fruits were sorted out to remove damaged ones and the firm tomato fruits were washed, drained and used for this experiment. The evaluation is carried out using the constructed proto-type tomatoes slicer, the performance of the tomato slicer in terms of output capacity, slicing efficiency and percentage damage were evaluated. Results show that the machine output capacity, slicing efficiency and percentage damage were 75% and 20% respectively. It is evident that the output capacity of the slicer is appreciable as a prototype compared to 377kg/hr output capacity of a full-blown construction reported by Raji and Igbeka (1994) and 32.51kg/hr reported by Kamaldeen and Awagu (2013) with different prime movers. The high efficiency recorded in this proto-type construction is an indicator that given the opportunity to be replicated in a full-blown construction, it will suit the requirement of large and medium scale dried tomato processors. The percentage damage which can be due to mechanical errors (wear and tear). The output capacity and the slicing efficiency of the slicer were determined using the relations in Agbetoye and Balogun (2009).

Output capacity (C_o).. 4.1

$$Co = \frac{WT}{T}$$

Where

Co = Output capacity (kg/hr)

WT= Total mass of tomatoes sliced (kg)

T = Time taken (h)

ii. Slicing efficiency. (n)…………………………………………………….....…4.2

$$\eta = \frac{Ws - Wd}{Ws} \times 100\%$$

Where,

η = Slicing efficiency (%)

Ws = Weight of all sliced materials (kg)

Wd = Weight of damaged sliced materials (kg)

iii. Percentage damage was determined using equation (%)…………………..4.3

$$Dp = \frac{Wd}{WT} \times 100\%$$

Where,

Dp =Percentage damage (%)

Wd= Weight of crushed tomato (Kg)

WT= Total weight of tomato (kg)

Using the formulas above to determine the output capacity, slicing efficiency and percentage damage

1) Consideration of Output Capacity

$$C_o = \frac{WT}{T}$$

Where:

WT = Total mass of tomatoes (kg) = 85kg

T = Time taken (h) = 1hr

$$Co = \frac{85}{1} = 85kg/hr$$

2) Consideration of Slicing Efficiency

$$\eta = \frac{Ws - Wd}{Ws} \times 100\%$$

Where:

Ws = weight of all sliced materials (kg) = 63kg

Wd = weight of damaged sliced materials = 22kg

η = Slicing Efficiency (%)

$$= \frac{68 - 17}{68} \times 100\%$$

$$= \frac{51}{68} \times 100$$

$$\eta = 0.75 \times 100$$

$$\eta = 75\%$$

3) Consideration of the Percentage Damage

$$Dp = \frac{wd}{wT} \times 100\%$$

Where:

Dp = Percentage damaged (%)

wd = Weight of crushed tomato (kg) = 17kg

wT = Total weight of tomato (kg) = 85kg

$$Dp = \frac{17}{85} \times 100 \qquad Dp = 20\%$$

Conclusion and Recommendations

An electrically powered tomato slicer was constructed and tested and found to be efficient with the values obtained as follows: output capacity is 85kg/h, the efficiency is 75% and the percentage damage is 20%. In order to improve the slicing efficiency of the machine, it is recommended that the knife carriage should be redesigned to be more rigid. A motor with much slower speed than the one used is equally suggested, then the feeding unit should be increased to accommodate more tomatoes at a time.

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