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DEVELOPMENT OF A MOTORIZED TOMATO (*Solanumlycopersicum L.*) SLICER

S. K. Shittu*, M. Bello and N. D. Dangora
(Department of Agricultural and Environmental Engineering, Bayero University Kano, Kano, Nigeria)
[*]Corresponding author's e-mail address: skshittu.age@buk.edu.ng

Abstract
In an attempt to solve the problem associated with slicing of tomato which is an important operation required in tomato drying industries, a motorized tomato slicer was designed fabricated and tested. In tomato processing industry, slicing of tomato is usually done to increase the surface area of the product for effective drying. The machine was designed to slice tomatoes into recommended size of 20mmthick for fast drying. The slicer consists mainly of a feeding unit, cutting compartment, collection unit, power section and tool frame. Tomato fruits fed through the feeding unit go down to the cutting compartment by gravitational force and the reciprocating motion of slicing knives cut the fruits by shearing action. In the design of the tomato slicer, physical properties of UC-82B tomato variety were considered. Results of performance evaluation showed that the machine has anoutputcapacity of468kg/h, percentage loss of 28.40%, and slicing efficiency of 60.34%.

Keywords: Design, construction, evaluation, tomato, slicer

1. Introduction

Tomato (*Solanumly copersicum L.*)is an edible fruits 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 μg carotene, 507 μg lycopene, 22mg vitamin C and the energy value is 61 kJ (Roe *et al.*, 2013).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 use for tomato cultivation per annum (Bodunde *et al.*, 1993).

Tomato fruit is highly susceptible to spoilage owing to it 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 (1987) 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 isabout60% (Babalola *et al.*, 2010).Presently in Nigeria, slicing of tomato for the purpose of sun drying is a common practice for its preservation. Traditional method of slicing with knives is one of the widely adopted methods. This method is time consuming, full of drudgery, unhygienic and hazardous. To improve the processing method and enhance its hygienic level, there is need for mechanization of the slicing process.Researchers have developed slicers for many other crops, but tomato slicer is still rare. Raji and Igbeka (1994) designed, fabricated and tested a 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/h at efficiency of 94.40 % for 5 mm slices while 23.90 kg/h at efficiency of 83.40 % was obtained for 2 mm chips. Obeng (2004) developed a prototype mechanised plantain slicer. The plantain slicer work by placing peeled plantain on cutter and wooden meshes hinged at one end and free to swing at the other end is pressed against the plantain. Compressive force of meshes and the reaction forces of cutter facilitate the cutting. Sliced plantain pieces pass through the cutter spaces down into a collection unit. The plantain slicer takes 5-7 seconds to slice a finger of an average-sized plantain into chips of 2-3 mm in thickness as compared to 40-80 seconds using knife.Ugwuoke *et al*. (2014) designed and fabricated an electrically powered rotary slicer for raw plantain chips production. The machine works on shear cutting principle and has the capacity to produce raw plantain chips of uniform sizes. It slices up to a maximum of 70mm diameter finger of raw plantain in 2-3 seconds. However, throughput capacity of the two plantain slicers will be low due to: one-by-one feeding of plantain into the machines and the need for operator to hold on the plantain fingers throughout cutting period. Kamaldeen and Awagu (2013) designed and developed a tomato manual slicing machine. The machine operates on the principle of shearing force of moving knife against tomatoes placed on a stationary part of the machine.It was designed to cut tomatoes in 2cm thickness. The capacity of the machine was 540.09g per minute (32.41 kg/hr) and its performance efficiency was 70%.Kamaldeen*et al*. (2016) modified an existing manually operated tomato slicer and compared performance of the two machines. The machines worked basically on the same principle of shearing force of moving knife against tomatoes placed on a stationary part of the machine. Improvements in the new machine were in the form of the use of metals as the machine components instead of wood, improved cutting blades and provision of collection unit. The slicing efficiency and output capacity of newly developed slicer were 90.10 % and 3.79 kg/hr respectively.

One major limitation of the available slicing machines is low output capacity that cannot meet the needs of ever growing dried tomato industries. The low output capacity is due to low cutting speed and one-by-one or batch feeding system applied. Nevertheless in Nigeria, traditional method of slicing tomato fruits with knives which is time consuming, laborious, unhygienic and hazardous remained the widely adopted method by dried tomato processors.

Therefore in order to ameliorate the drudgery associated with traditional method, the objectives of this study were:

(1) To design, fabricate and carry out performance evaluation of a motorized tomato slicer
(2) To compare the outputcapacity of the tomato slicer with the manual method.

2. Materials and Methods

2.1 Materials

The tomato slicer was fabricated from locally available materials. These essentially include power screw, metal sheet, stainless blades, ball bearings and electric motor.

2.2 Design Considerations

The following considerations were taken into account during the design stages of the tomato slicer:

i. Stresses: static and dynamic stresses resulting from direct loading, bending and torsion were considered in power screw selection.
ii. Capacity: continuous flow feeding system that enhances high output capacity to suit the requirement of a large scale dried tomato processorswas adopted.
iii. Low cost of production by using locally available materials was considered.
iv. Uniformity of slices: recommended2 mm thick slice of tomato was considered for effective drying of products.
v. Ease of maintenance: parts that need frequent maintenance were not permanently fixed to the machine.
vi. Properties of tomato: physical and mechanical properties of UC- 82B tomato variety were considered in the design of the tomato slicer.

2.3Design of Machine Elements and Parameters

2.3.1Capacity of the feeding unit

Feeding unit of the tomato slicer was made from a rectangular plate having eight holes. Cylindrical pipes were welded to the hole on the plate to form columns in which tomatoes to be sliced drop by gravity and slight agitation of the machine into the slicing unit. The rectangular plate is 500mm x 200mm (assumed size). Average major diameter of UC-82B variety of tomato is 47.51mm (measured) hence eight holes of 60mm diameter were used for the column so that larger tomato sizes can be accommodated. The columns were therefore 60 mm diameter and 110 mm long. Each of columns was made such that it can accommodate 6 tomatoes at a time. Therefore, feeding unit has the capacity:$6\,Tomatoes \times 8\,Holes = 48\,Tomatoes.$

Using the average mass of the UC – 82B Tomato= $50.76\,g$(Measured)

The total weight carried by the slicing chamber = average mass of tomato × total number of tomatoes $= 50.76 \times 48 = 2436.48\,g$

2.3.2 Capacity of the collection unit

Collection unit of the tomato slicer was made from sheet metal plate. It has a trapezoidal container shape. Volume of the collection unit can be determined from the equation (1) given as:

$$V_c = \frac{LH(A+B)}{2} \quad (1)$$

where:

$V_c =$ Volume of collection tray(mm^3) $L =$ length of tray (mm)

$H =$ height of tray (mm)

$A =$ Length of the longer side of the trapezium (mm)

$B =$ Length of the shorter side of the trapezium (mm)

Therefore,

$$V_c = \frac{610 \times 110(310 + 150)}{2}$$

$$V_c = 15{,}433{,}000\,mm^3$$

2.3.3 Power screw design

The machine was designed to use a power screw which moves a nut that carries tomato cutting blades in a horizontal plane. Acme threaded shaft of 18mm outer diameter made from mild steel was selected based on rigidity to carry the cutting blades. Using the basic dimensions for Acme threads as given by Khurmi and Gupta (2005), the shaft has following parameters:

$d_o = 18$ mm, $d_c = 13.5$ mm, $p = 4$ mm and $A_c = 143$ mm^2

where:

d_o = outer diameter of the shaft (mm)

d_c = minor or core diameter of the shaft (mm)

p = thread pitch (mm)

A_c = area of core(mm^2)

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

$$P_m = T \times \omega \quad (2)$$

(Khurmi and Gupta, 2005)

Where,

P_m=Power of the motor (W)

T= Torque required to operate the screw (Nm)

ω= angular speed (rad/s)

But Torque (T) is given as:

$$T = P \times \frac{d}{2} \quad (3)$$

Where,

P= tangential force at the circumference of the screw (N)

d= mean diameter of the screw (m)

P is given as:

$$P = Wtan(\propto + \emptyset) = W\left[\frac{tan \propto + tan\emptyset}{1 - tan \propto tan\emptyset}\right] \quad (4)$$

Where,

W = load to be lifted by the screw (N)

$\propto$ =coefficient of friction between screw and nut

$\emptyset$=angle of friction (coefficient of friction is given as $\mu = tan\emptyset = 0.15$)(Khurmi and Gupta, 2005).

Determination of load to be lifted by the screw (W)

Mass of carriage $= 0.80\ kg$ (measured)

Therefore, force due to carriage = 0.80 kg x 9.81 m/s^2 = 7.85 N

Mass of each blade$= 0.19\ kg$ (measured)

Therefore, force due to the two blades$2 \times 0.19\ kg \times 9.81\ m/s^2 = 3.72\ N$

Mass of a nut$= 0.0024\ kg$ (measured)

Therefore, force due to the four nuts$= 4 \times 0.0024\ kg \times 9.81\ m/s^2 = 0.094\ N$

Cutting resistance of tomato fruits

Maimunahtu (2005) gave maximum shearing resistance of tomato fruit as $0.4750\ N/mm$
Measured average major diameter of UC-82 variety of tomato is $= 47.51\ mm$
Shearing resistance of a tomato is therefore, $= 0.4750\ \times 47.51 = 22.57\ N$
But the slicer is designed to cut through two (2) tomatoes at a time
Therefore, force resistance of tomatoes $= 2\ \times 22.57 = 45.13\ N$

$W = 7.85\ + 3.72\ + 0.094\ + 45.13$

$W = 56.79\ N$

Equation for coefficient of friction $\propto$

$$\tan \propto = \frac{p}{\pi d} \quad (5)$$

But mean diameter (d) of the power screw can be determined from equation (6) as given by Khurmi and Gupta (2005) as:

$$d = d_o - \frac{p}{2} \quad (6)$$

Therefore,

$$d = 18 - \frac{4}{2}$$

$$d = 16\ mm$$

Hence, from equation (5)

$$\tan \propto = \frac{4}{3.142 \times 16}$$

$$\tan \propto = 0.0796$$

2.3.4 Electric motor power estimation

From equation (4)

$$P = 56.79 \left[\frac{0.0796 + 0.15}{1 - 0.0796 \times 0.15}\right]$$

$$P = 13.20\ N$$

Hence, torque from equation (3) is

$$T = 13.20 \times \frac{16}{2}$$

$$T = 105.60\ Nmm \text{ or } 0.106\ Nm$$

$$\omega = \frac{2\pi N}{60} \quad (7)$$

It is desired that the tomato be cut at a speed (v) of 0.08 m/s = 4800mm/min.

$$N = \frac{v}{p} = \frac{4800}{4} = 1200\ rpm$$

Therefore,

$$\omega = \frac{2 \times 3.142 \times 1200}{60}$$

$$\omega = 125.68\ rad/s$$

From equation (2)

$P_m = 0.106 \times 125.68$
$P_m = 13.32$ W
$P_m = 0.01332$ kW
But the capacity of prime mover required by the machine can be obtained from the equation (8) as given by Mohammed and Hassan (2012).

$$P_r = \frac{P_m}{\eta} \tag{8}$$

Where,
P_r = capacity of prime mover required (kW)
$\eta = 0.85$, assumed drive efficiency
Therefore,

$$P_r = \frac{0.01332}{0.85}$$

$P_r = 0.016\ kW$ (0.012 hp)
The closest size available electric motor of 0.25 hp with the speed of $1200 rpm$ was employed.

2.4 Machine Description and Working Principle

2.4.1 Machine description

The tomato slicer presented as presented in Figures 1 and 2comprises of different units, these include: Tomato feeding unit, slicing unit, collection unit, power unit and frame. The machine is mainly from mild steel. It is rectangular in shape with length of 940 mm, width of330 mm and height of 500 mm. The feeding unit of the tomato slicer is made up of a rectangular sheet metal plate having 8 holes on which cylindrical pipes (60 mm diameter and 110 mm long) were welded to form vertical columns in which tomatoes to be sliced are fed into the machine. Each of the columns can take 6 tomatoes; therefore the feeding unit takes about 48 tomatoes at a time. Tomato fruits in the columns drop by gravity onto the slicing unit. The slicing unit consists of a metal plate, power screw and blade carriage all made of mild steel and two slicing blades made from stainless steel. The metal plate is a rectangular of820mm x 270mm. It is the surface on which the tomatoes dropped. The plate is horizontally placed 20 mm away from the bottom of vertical columns in the feeding unit. The power screw is Acme threaded shaft of 18 mm outer diameter, 4 mm pitch and 660 mm long. It converts rotary motion of the prime mover to translatory motion of the blades. The power screw 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 screw by a nut which moves axially. The nut carries the carriage together with the blades forward and backward as the power screw is rotated by the prime mover in the clockwise and anticlockwise directions. There is 20 mm gap between the bottom of vertical columns and metal plate which give the thickness of the sliced tomato as recommended by Isiaka (2009). The collection unit made from sheet metal plate is trapezoidal in shape. It has a total volume of15,433,000 mm^3. The power unit comprises of an electric motor 0.25hp and 1200rpmwhich can rotate in both clockwise and anticlockwise directions 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.

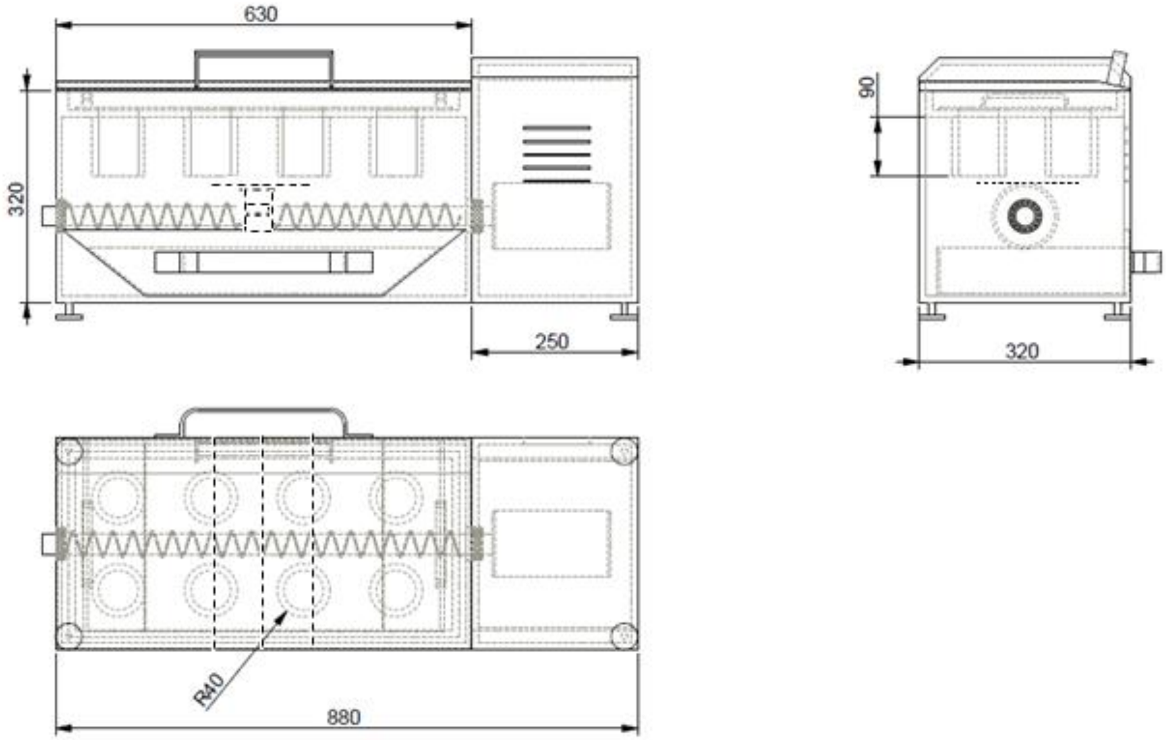

Figure 1: Orthographic projection of tomato slicer

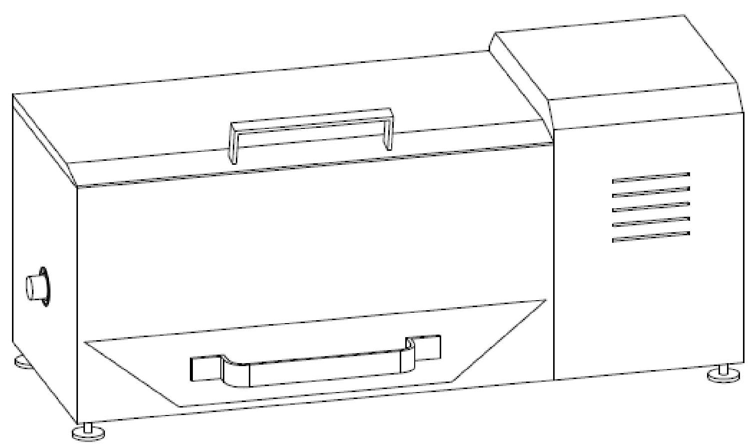

Figure 2: Isometric view of tomato slicer

2.4.2 Working principle

The tomato slicer presented in Plate 1 is operated by switching on the electric motor which drives the stainless blades on the horizontal plane inside the slicing unit. The blades move forward or backward 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 metal plate in the slicing unit and other fruits queue up in the vertical columns. The blades cut the fruits on metal plate by shearing action. One of the blades slices the fruits during forward strokes while the other slices during backward strokes. The sliced tomatoes are moved to the collection tray by sweeping action of the flange below the blades. The next sets of tomato fruits in the column drop onto the metal plate and the process is repeated.

Plate 1: Tomato Slicer

2.5Performance Evaluation of the Machine

2.5.1 Tomato fruits samples

A basket of matured tomato fruits of UC – 82B variety was procured from a farm at KonarGafan in GarunMallam LGA of Kano State, Nigeria. The fruits were sorted to remove damaged ones and the firm tomato fruits were washed, drained and used for experiments. The evaluation layout was done in a factorial experiment using complete randomized design (CRD) with a single factor, which is slicing method at two levels. The methods were: manual slicing with knife and the use of the designed and fabricated tomato slicer. The experiments were replicated five times. Using the expressions in equations 9-11, the performance of the tomato slicer in terms output capacity, slicing efficiency and percentage damage were determined and average values were recorded.Analysis of variance ANOVA was used to test the effect of the slicing methods on the output capacity using GLM of SAS 9.2 Software package (SAS Institute Inc., 2008). Post hoc tests were carried out using the least significance difference (LSD) for further comparison of the factors of the independent variables.

The outputcapacity and slicing efficiency of the slicer were determined using the relations in Agbetoye and Balogun (2009)

(i) Output Capacity (C_o)

$$C_o = \frac{W_T}{T} \tag{9}$$

Where,

C_o = Output capacity (kg/h)
W_T = Total mass of tomatoes Sliced (kg)
T = Time taken (h)

(ii) Slicing efficiency (η)

$$\eta = \frac{W_S - W_d}{W_S} \times 100\% \quad (10)$$

Where,
η = Slicing efficiency (%)
W_S=weight of all sliced material (kg)
W_d= weight of damaged sliced materials (kg)

(iii) Percentage damage was determined using equation (11).

$$D_P = \frac{W_d}{W_T} \times 100\% \quad (11)$$

(Ikejiofor and Eke-okoro, 2013)
Where,
D_P = Percentage damage (%)
W_d =Weight of crushed tomato (kg)
W_T =Total weight of tomato (kg)

3. Results and Discussion

Results show that the mean values of machine outputcapacity, slicing efficiency and percentage damage were 468 kg/h, 60.34% and 28.40% respectively. It is evident that the output capacity of the slicer is higher than capacity of 377 kg/h reported by Raji and Igbeka (1994) and 32.41 kg/hr reported byKamaldeen and Awagu (2013) although their prime movers were all different. The high output capacity suits the requirement of large/medium scale dried tomato processors. Slicing efficiency of the tomato slicer is lower but not too far from the efficiency of 70% obtained by Kamaldeen and Awagu (2013). Low slicing efficiency and high percentage damage obtained can be attributed to wobbling action of the blade carriage observed during performance tests.Table1 presents the outputcapacity of manual and the tomato slicer. It can be seen that for 5 different experiments using 5kg per batch of tomatoes, mean values of outputcapacity were consistently higher for tomato slicer than manual method. This shows that substantial improvement was achieved with the machine. The results of the analysis of variance are presented in Table 2.

Table1: Output capacity of tomatoes using different methods

Experiment Number	Output capacity of tomatoes (kg/h)	
	Manual/knife	Tomato slicer
1	137.61	526.32
2	188.68	344.83
3	140.85	500.00
4	142.86	508.47
5	135.75	461.54
Average	149.15	468.23

Table 2: Analysis of Variance(ANOVA)showing effect of slicing methods on output capacity

Source	DF	Sum of Squares	Mean Square	Computed F-value	Pr> F
Experimental Number	4	5654.0654	1413.5164	0.32^{ns}	0.8515
Slicing Method	1	254533.3068	254533.3068	57.83^{*}	0.0016

^{ns}Not significant *Significant at 5% level of significance

The table shows that slicing method has significant effect at 5% probability level on the output capacity. This implies that the quantity of tomatoes sliced per unit time for both methods are appreciably different from each other. To know the trend of the difference, a post-hoc using the least significance difference LSD was carried out and the result of post-hoc is presented in Table 3.

Table 3: LSD Test for effect of slicing methods on output capacity

LSD	Output capacity (kg/h)	Slicing Method
A	468.23	Slicing machine
B	149.15	Manual Slicer

The mean values of the output capacities of the tomato slicer and manual slicing were 468.23 and 149.15 kg/hr respectively. The results revealed that the mean value of outputcapacity of the tomato slicer is significantly higher than manual slicing at 5% probability level.

4. Conclusion

A motorized tomato slicer was developed, tested and compared with manual slicing method. The slicing methods under consideration have significant effect onoutput capacity. Output capacities were consistently and statistically higher for tomato slicer than manual method. The mean values of the output capacities of the tomato slicer and manual slicing were 468.23 and 149.15 kg/hr respectively. Slicing efficiency and percentage fruits damage for the tomato slicer were 60.34% and 28.40% respectively. In order to improve the slicing efficiency of the machine, it is recommended that the knife carriage should be redesigned to be more rigid.

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