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Design, Construction and Performance Evaluation of a Motorized Tomato Slicing Machine

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Abstract
One of the major methods of tomato preservation is drying before storage. Tomatoes are best dried when sliced, the manual means of slicing tomato using knife is energy and time consuming and of course prone to injury when not done carefully. To solve the problems encountered in slicing of tomatoes**,** a motorized tomato slicing machine which is capable of conserving human energy, reducing time spent in slicing, providing safety as well as hygiene to users and serves as a source of income to small and medium scale farmers was designed, constructed and tested. Fully riped tomato sample was obtained and classified into three (Large, medium and small), evaluation of the machine performance was done based on the classifications and slicing efficiency, output capacity and percentage damage were calculated. The machine was designed to cut tomatoes into slices of 2.45cm thickness. The percentage damage, slicing efficiency and output capacity for large, medium and small tomatoes were 3.33%, 93.33% and 179.25kg/hr, 5%, 88.33% and181kg/hr, 5%, 81.67% and 178kg/hr respectively. The results of the study showed that the motorized machine can slice tomatoes effectively and satisfactorily.
Keywords: Preservation; Slicing; Drying; Motorized; Efficiency.

I. INTRODUCTION

Tomato (*Solanumlycopersicum L.*) is one of the most popular produce and extensively consumed vegetable crop in the world[1]. It can be eaten raw in salads or as an ingredient in many dishes and in drinks [2]. Tomatoes and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body. Tomato contains high amount of lycopene, a type of carotenoid with anti-oxidant properties [3] which is beneficial in reducing the accidence of some chronic diseases [4] like cancer and many other cardiovascular disorders [5]. Other studies have also shown that consumption of tomato and tomato-based foods can be linked to reduce incidence of a variety of cancers in general, including pancreatic, lung, stomach, colorectal, oral, bladder, and cervical cancer [6]. Over 45% (750,000 metric tons) of tomatoes produced in Nigeria is estimated as annual loss due to poor food supply chain management, price instability resulting from seasonal fluctuation in production [7]. Therefore, it is very important to process and preserve tomatoes to ensure its availability during off season.

II. MATERIALS AND METHODS

2.1 Materials
Materials used in the construction of motorized tomato slicing machine includes mild steel, stainless steel, cast iron, Gear motor, Electric motor, Synthetic Rubber and bearings etc.

2.2 Design Consideration
A number of factors were considered in the design of the machine which includes:
i- Functional requirement
ii- Cost effective factors
iii- Reliability factors
iv- Resistance to environmental factors

2.3 Design Calculation
The motorized tomato slicing machine was designed and constructed. The description of its various units are as follows:

- ***Shape and Size of Tomato***

Tomatoes are usually round, oval and cylindrical in shape and have a diameter ranging between 30mm to 80mm depending on the type. Shape and size are important in the design of components that handles the tomatoes like the hopper, the conveyor, knives arrangement and particularly the inner and outer clearance. The clearance should be slightly larger than the thickness of the tomato to allow the free passage and movement of the tomato.

- ***Design of Hopper***

The hopper is made up of four welded metal sheets slanting towards an opening to form a trapezium. It has two openings; the larger upper opening is for introducing the tomato while the smaller lower opening connects the hopper to the conveying unit. The capacity of the hopper is 2.5kg of tomatoes.

- ***Belt Conveyor Speed, Capacity and Length***

The conveyor belt is found in the conveying unit which is powered by an electric motor via a gear motor. The belt conveyor is made of canvass material for the belt, rollers, bolts and nuts for the tomato support. The speed of the conveyor is given by

$$V = \pi D \quad (1)$$

Where:
V = belt speed, m/s
D = diameter of roller in, m

Capacity is the product of speed and belt cross sectional area. Generally, belt capacity (kg/sec) is given by:

$$BC = 3.6 \times A \times \rho \times V \quad (2)$$

Where:
BC = belt capacity, kg/s
A= belt sectional area (m2);
ρ = material density (kg/m3); and
V= belt speed (m/s)

Length of the belt is given as:

$$L = \frac{\pi}{2}(D1 + D2) + 2C \quad (3)$$

- ***Shaft Design***

The material for the design of the shaft is very important as it contributes to the strength and rigidity of the shaft. In this design mild steel was used because it is available, economical and can give required strength. From the power transmission, various members such as pulleys and others are mounted on the shaft. [8] has given the formula for the determination of the minimum diameter (D) of a shaft loaded in torsion and bending as the shaft will be subjected to combine torsional and bending.

$$D^3 = \frac{16}{\pi\tau}\sqrt{(Kt \times Mt)^2 + (Kb \times Mb)^2} \quad (4)$$

Where:
Kt = combined shock and fatigue factor applied to torsional moment (Kt=1)
Kb = combined shock and fatigue factor applied to bending moment (Kb=1.5)
Mt = torsional moment (Nm)
Mb = bending moment (Nm)
τ = allowable mild steel shear stress of shaft (Nm-2)

- ***Determination of Pulley Diameter***

The allowable diameter of the pulley was obtained using the expression given by [9].

$$N_1 D_1 = N_2 D_2 \quad (5)$$

Where,
N_1 = speed of driving motor, rpm
N_2 = speed of driven shaft, rpm
D_1 = diameter of driving motor pulley, mm
D_2 = diameter of driven pulley, mm

The belt speed (V) was obtained from the equation below as:

$$V = \pi N_1 D_1 / 60 \quad (6)$$

Where: V = velocity, m/s

- ***Determination of Belt Length***

The belt length was obtained using equation of [10] as:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D2 - D1)^2}{4C} \quad (7)$$

Where:
L = length of belt, mm
C = distance between the center of driving and the driven pulleys, mm
D1 = diameter of driving pulley, mm
D2 = diameter of driven pulley, mm

- ***Angle of Contact between the Belt and Pulley***

Angle of contact is the angle of contact at the smaller pulley. It can be obtained from the equation below as given by [10]

$\theta = (180° - 2\alpha)\frac{\pi}{180}$ (8)

$\sin\alpha = \frac{r_1 - r_2}{C}$ (9)

Where:
θ = angle of contact in radians
α = Wrap angle of the smaller pulley in degree
r_1 and r_2 = radii of the driving and driven pulleys respectively, mm
C = distance between the center of driving and the driven pulleys, mm

- ***Tension in Belt***

The relationship between the tight and slack tensions in term of coefficient of friction (μ) and the angle of contact is given by [10] as:

$2.3\log(T_1/T_2) = \mu\Theta$ (10)

Where:
T_1 = Tension in the belt on the tight side, N
T_2 = Tension in the belt on the slack side, N
μ = Coefficient of friction between the belt and pulley = 0.25
θ = angle of contact in radians

- ***Power Requirement***

An electric motor of 2hp with 1430rpm was used to operate the slicing machine.

$P = T \times \omega$ (11)

$\omega = \frac{2\pi NT}{60}$ (12)

Where;
T=torque, Nm
ω =speed in radians
N= speed of shaft

- ***Weight of Knives***

The weight of the knives is affected by the length, width, thickness and density of the material used. Thus, the selection of right length, width and thickness of slicing knife is very essential as it directly affects the slicing effectiveness. The weight of slicing knife was calculated using expression given by [10]:

$W_k = L_K \times W_K \times t_K \times \rho_K \times g$ (13)

Where:
W_k= knife weight, N
t = knife thickness, m
L_k = Knife length, m
w= Knife width
g = acceleration due to gravity, m/s2
ρ = knife density = Kg/m3

- ***Impact Force Required to Shear Fresh Tomato***

Considering the shear strength of fresh tomato and area under shear, the impact force required to shear fresh tomato may be obtained from the following expression:

$F_T = A_T + \tau_T$ (14)

Where:
F_T = Force required for shearing fresh tomato
A_T= Area under shear
τ_T = Shear strength of the compressed tomato

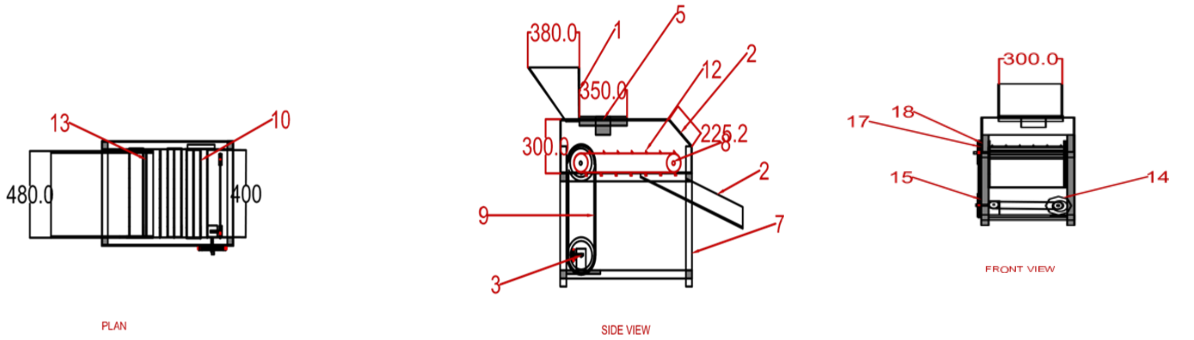
The area under shear can be determined using the following equation;

$A_T = \frac{\pi D^2}{4}$ (15)

The area of larger tomatoes of thickness ranging from 0-62 mm and the equivalent diameter can be calculated by the following expression given by [11]:

$D_T = [L\ X\ \frac{(W+T)^2}{4}]^{1/3}$ (16)

Where:
D_T= Equivalent diameter of the tomato, in (cm)
L = Length of the tomato, in (cm)
W = Width of the tomato, in (cm)
T = Thickness of the tomato, in (cm)



S/N	Description	Material	No	Remark
1.	Hopper	Metal sheet	1	
2.	collection point	stainless steel	1	
3.	Gear motor		1	
4.	Conveyer belt	canvass	1	
5.	Opening	Metal sheet	1	
6.	shaft	Mild steel	2	
7.	frame	mild steel angle	1	
8.	Roller	Mild steel	2	
9.	Firm belt	synthetic rubber	2	
10.	fin-pusher holder	rubber	16	
11.	Pulley		3	
12	Cover	Metal sheet	1	
13.	Fin-pusher	stainless steel	128	
14.	Electric motor pulley	cast iron	1	
15.	Gear motor pulley on electric motor side		1	
16.	Gear motor pulley on conveyor side		1	
17.	pulley on conveyor belt		1	
18.	pedestal bearing			

Figure 1: Tomato Slicer Assembly

2.4 Experimental Procedure

The machine was switched on and allowed to run without load for some minutes to ensure t it is in good working condition. 2.5kg of large size tomato sample was measured using a weighing balance. The measured 2.5kg sample was fed into the hopper to the conveying unit where it is conveyed to the cutting unit. Time taken to slice the 2.5kg of large tomato sample was recorded. The sliced and unsliced tomatoes were counted and weighed using the weighing balance. The procedure was replicated three (3) times. The slicing efficiency (SE), output capacity (OC) and percentage damage were calculated and recorded. The same procedure was carried out for medium and small size tomato samples.

III. PERFORMANCE INDICES FOR SLICING MACHINE

The performance indices used were slicing efficiency, output capacity and percentage damage.

- ***Slicing efficiency***

The slicing efficiency measures how effective the tomatoes were sliced by the slicing machine. It is calculated using expression given by [12]**:**

$$S.E = \frac{T_S}{T_f} \times 100 \quad (17)$$

Where:
T_s = Total number of tomatoes sliced correctly
T_f= Total number of tomatoes fed into the machine

- ***Output capacity***

Output capacity of the slicer measures of the quantity of the slicer can handle per unit load of operation. It is calculated using expression given by [12]**:**

$$O.C = \frac{W_T}{T} \quad (18)$$

Where:
W_T = total weight of tomato fed into the machine in (kg)
T = total average time taken to sliced all the tomato fed into the machine (s).

- ***Percentage damage***

The damage percentage of the slicing machine is a measure of a level damage done by the slicing machine. It is calculated using the following expression given by [12]:

$$D_P = \frac{W_d}{W_t} \times 100 \quad (19)$$

Where:
D_P = damage percentage, %
W_d = total number of tomatoes feed into the machine
W_t= total number of tomatoes damage

IV. RESULT AND DISCUSSION

Table 1 Shows the mean values of length, thickness and width of the tomato sample before slicing which was used for obtaining suitable sizes that will give effective and uniform slices. From the evaluation, the largest sizes have higher efficiencies, this is because large size got enough shearing surface area exposed to the cutting element (knives)[13].It could also be observed that the Output capacities of medium and largest sizes are more compared to small ones and finally, it was found that the machine is capable of slicing tomatoes with minimum damage, slicing efficiency and output capacity of 3.33%, 93.33% and 179.25kg/hr., 5%, 88.33% and 181kg/hr., 5%, 81.67% and 181kg/hr. for large, medium and small tomatoes respectively. It produces slices of uniform thickness with standard deviation and variance of 22.5 and 507.5, 22.8 and 517.7 and 22.6, 507.5, 22.8 and 517.7 and 22.6, 22.6 and 507.5 for large, medium and small respectively.

Table 1: Mean values of Tomato dimension (Length, thickness, width)

Properties	Large 62 mm	Medium 52 mm	Small 44 mm
L	57	47	41
T	62	52	44
W	56	44	41

Table 2: Slicing efficiency for Tomato sizes

S/N	Efficiency for large tomatoes (%)	Efficiency for medium tomatoes (%)	Efficiency for small tomatoes (%)
1	86.67	93.33	73.33
2	93.33	80.00	93.33
3	93.33	86.67	93.33
4	100.00	93.33	66.67

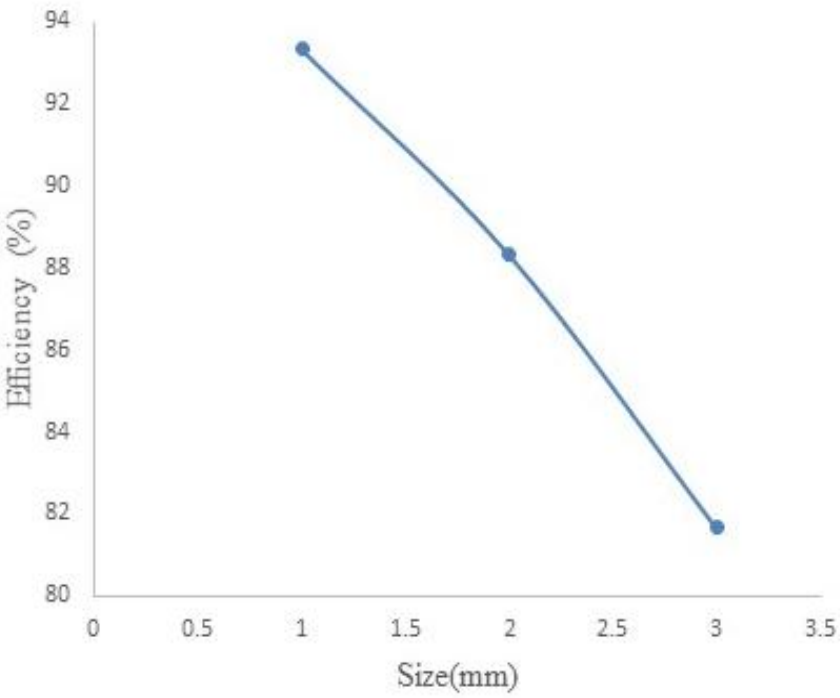


Figure 2: Relationship between slicing efficiency and tomato size

Table 3: Output capacity of Tomato sizes

S/N	Output capacity (kg/hr.) Large Tomatoes	Output capacity (kg/hr.) Medium Tomatoes	Output capacity (kg/hr.) Small Tomatoes
1	177	187	187
2	178	175	180
3	184	187	177
4	178	175	170

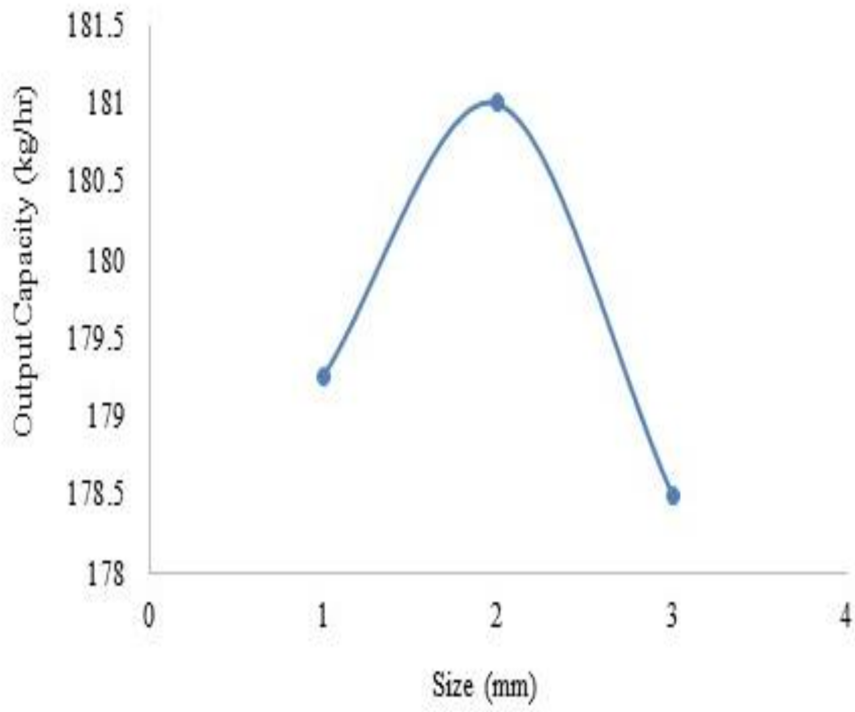


Figure 3: Relationship between output capacities and tomatoes sizes

Table 4: Percentage damage

S/N	% damage for large tomatoes	% damage for medium tomatoes	% damage for small tomatoes
1	13.33	6.67	6.67
2	0.00	6.67	0.00
3	0.00	0.00	0.00
4	0.00	6.67	13.33

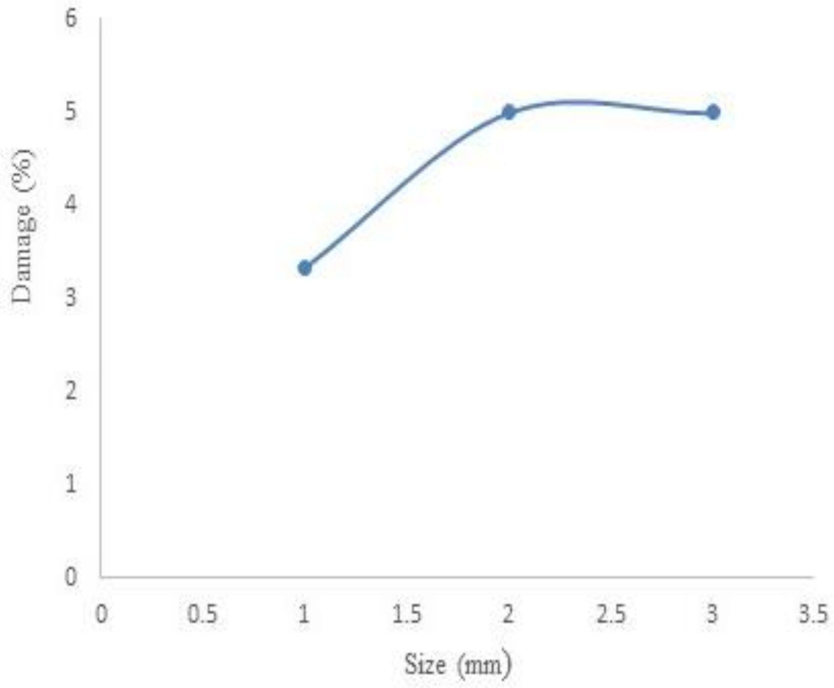


Figure 4: Relationship between damage and tomatoes sizes

V. CONCLUSION

The motorized tomato slicing machine was designed, constructed and evaluated based on three different sample sizes of tomato. It was found that the machine is capable of slicing tomatoes with slicing efficiency, output capacity and minimum damage of 93.33%, 179.25kg/hr and 3.33%, 88.33% ,181kg/hr, and 5%, 81.67%, 181kg/hr and 5%, for large, medium and small tomatoes respectively. It produces slices of uniform thickness with standard deviation and variance of 22.5 and 507.5, 22.8 and 517.7 and 22.6, 507.5 for the sizes respectively. The machine offers important contribution in conserving human energy, reducing time spent in slicing, providing safety as well as hygiene to users and serves as a source of income to small and medium scale farmers.

VI. RECOMMENDATIONS

The following recommendations are suggested for further studies:

- Provision of wheels instead of stand to ease pulling or pushing
- Provision of grading mechanism for grading the tomatoes before getting into the slicing chamber
- Hygiene should be given attention when selecting construction materials for mass production
- More factors affecting the efficiency and effectiveness of the machine need to be explored.

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