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Development of a turmeric slicing machine

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Abstract
This study was to develop a turmeric slicing machine in order to improve the slicing efficiency of fresh turmeric. A turmeric slicing machine was designed, fabricated, and evaluated. The slicing unit consists of cylinder, piston, collecting rod, cam, blades, blades separator, and blade holder. The slicing of turmeric was effected using reciprocating principle with fixed blade powered by an electric motor. The spacing of the blade was made 7mm to achieve uniform slices of turmeric. The blade was removable for easy cleaning and for replacement with blade of varying sizes for the slicing machine to achieve desired slicing. The machine was evaluated with turmeric rhizomes for slicing efficiency (S.E) and percentage of non-uniform slice. The slicing efficiency, non-uniform slice and capacity of the machine for slicing turmeric obtained were 59.8%, 40.2% and 34.3 kg/h respectively.

Keywords: Development, Turmeric, Blade, Slicing, Slicing efficiency, Non uniformity slice

Introduction
Many of natural plant products have pharmacological or biological activities that can be exploited in pharmaceutical drug discovery and drug design. Medicine derived from plant have played a pivotal role in the health care of many cultures, both ancient and modern (Newman *et al.*, 2003; Butler, 2004; Balunas and Kinghorn, 2005; Gurib-fakin, 2006, Newman and Cragg, 2007). The Indian system of holistic medicine known as "Ayurveda" uses mainly plant-based drugs or formulations to treat various ailments, including cancer. Turmeric (curcuma longa) is characterized by its tuberous rhizome. The exterior can be yellow, tan or olive green colored, while the interior, which is hard and firm, is either Orange-brown or deeply rust color with transverse resinous parallel rings (Schonbeck and Frey, 2005). Turmeric is best preserved in the dried form by processing into flour, chips and pellets for both human and livestock consumption. Turmeric is often sliced before cooking and steaming, either for direct consumption or as one step in a processing system. The process of cutting or slicing turmeric known as size reduction gives rise to faster cooking. The reduction in size is brought about by mechanical means without change in chemical properties. The slices produced by traditional methods are not uniform and this may result in non-uniform drying or infected dried slices. With technological advancement, there is progressive increase

in awareness of the importance of using mechanical devices to slice agricultural produce. Due to high demand for root and tuber crops for various domestic uses, it became imperative that slicing machine to slice these root and tuber crops be developed. Slicing method of turmeric can be done manually or mechanically. Manual means is time consuming, tedious and limit the production per time. It is therefore desirable to improve on the slicing means of turmeric processing by designing and fabricating a turmeric slicing machine, which is capable of slicing at a precise dimension, fast enough, last longer in use with constant high efficiency, harmless to the fingers and at the same time portable and affordable for purchase by small scale farmer, businessmen and individuals.

Materials and methods

The materials used in the construction of the turmeric slicing machine are stainless steel, angle iron and wood. These materials were chosen based on their resistance to corrosion, malleability and low density.

Design Criteria and consideration

Turmeric possesses some unique characteristics which were taken into consideration in designing the slicer. Turmeric rhizomes have irregular shapes and sizes. They have fingers and are highly fibrous. The machine is to be powered by electric motor. The component parts of the machine include hopper, barrel/housing, piston, connecting rod, cam, blades, blade separators, blade holder, frame, stand and switch. The machine parts were constructed using locally sourced materials.

The following assumptions were made in designing the Turmeric slicing machine:

- The driving shaft of the slicing chamber and material must be able to withstand the combined torsion and bending moment based on maximum shear theory.
- The maximum load on the hopper must not exceed 20N considering the machine's hopper volume capacity to be handled per batch of loading.

Design calculations

These are the calculations required in the construction of some component parts of the machine.

1 Hopper Design (No Load)

The hopper is in the shape of a cone and it was calculated using equation 1 given by Khurmi (2009)

$$V_{hopper} = \frac{\pi \ x \ r \ x \ r \ x \ h}{3} \qquad (1)$$

Where:

V_{hopper} = Hopper volume, m^3

R = hopper radius, m

H = hopper height, m

$$V_{hopper} = \frac{3.142 \ (0.05 \ x \ 0.05) x \ 0.09}{3}$$

$V_{hopper} = 2.4 \ x \ 10^{-4} \ m^3$

The hopper weight (W_h) was calculated using equation 2 given by Khurmi (2009)

$W_h = \rho \ x \ V \ x \ g \qquad (2)$

$W_h = 7850 \ x \ 0.00024 \ x \ 10 = 18.84N$

The Turmeric weight (W_T) is given by Khurmi (2009)

$W_T = \rho \ x \ V \ x \ g$

Where:

W_T = Weight of the Turmeric, N

ρ = Density of the hopper material (Galvanize steel), kg/m^3

g = Acceleration due to gravity, m/s^2

$W_T = 1358 \times 2.4 \times 10^{-4} \times 10 = 3.3N$

Where:

W_h = Weight of the hopper, N

2 Hopper Design (Under Load)

Weight on the hopper under load (W_L) was calculated using equation 3.

W_L = Weight of the hopper (W_h) + Weight of Turmeric (W_T) (3)

$W_L = 18.84N + 3.3N$

$W_L = 22.14N = 22N$

3 Design of Cylinder (Slicing Chamber)

Volume of cylinder was calculated using equation 4 given by Khurmi (2009)

$V_{cylinder} = [\pi(ro^2 - ri^2)h - (l \times b \times t)opening]$ (4)

Where:

$V_{cylinder}$ = Volume of cylinder, m^3

R_o, r_i = Radii of outer and inner cylinder respectively, m

h = Height of cylinder, m

l = Length of cylinder, m

b = Breadth of cylinder, m

t = Thickness of cylinder, m

W = weight of the cylinder, N

$V_{cylinder} = [\pi(0.105^2 - 0.01025^2) \times 0.6 - (0.15 \times 0.15 \times 0.0025)]$

$V_{cylinder} = 9.22 \times 10^{-4} m^3$

The cylinder weight (W) was determined using equation 5 given by Khurmi (2009)

$W = \rho \times V \times g$ (5)

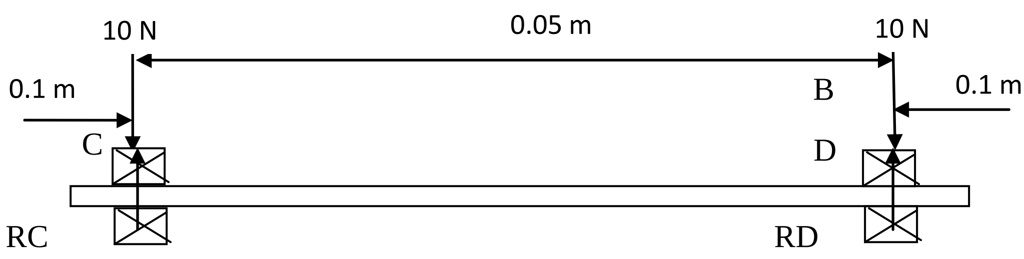
Where:

ρ = density of the cylinder material, (Galvanized steel), kg/m^3

g = acceleration due to gravity, m/s^2

$W = 7850 \times 9.22 \times 10^{-4} \times 10 = 72.38N$

4 Design of Hopper Shaft



W = 10 N (half of the hopper capacity/weight)

L = 0.1 m = 100 mm

X = 0.05 m

Maximum bending moment acts at C and D

M= W x L
Where:
W = Weight acting on the hopper, N
L = Distance outside the hopper base, m
M = 10 x 0.1 = 1 Nm.

5 Torque Requirement Design

Torque was calculated using equation 6 given by Khurmi (2009)

Torque = Force x shaft radius (6)
= 22 x 0.1 = 2.2Nm

6 Design of Power

Power was calculated using equation 7 given by Khurmi (2009)

Power = 2^{π}NT (7)

Where:

π = Constant (3.142)
N = Number of revolution, rpm
T = Torque, Nm
Number of revolutions (N) = 350 (Murumkar *et al*., 2016)
Power = 2 x 3.142 x 350 x 2.2
= 4838.68 W = 4.8kW

7 Shaft Diameter Design

Shaft diameter was determined using equation 8 given by Krutz *et al.* (1984)

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_m M)^2 + (K_T T)^2} \quad (8)$$

Where

M = Maximum bending moment, Nm
T = Maximum torque, Nm
S_s = Allowable shear stress = 41.379 x 10^6 N/m^2
K_m and K_T = Shock loading factors
d = Shaft diameter, m

$$d^3 = \frac{5.1}{S_s}\sqrt{(K_m M)^2 + (K_T T)^2}$$

$$d^3 = \frac{5.1}{41.379 \times 10^6}\sqrt{(2.0 \times 1)^2 + (1.5 \times 2.2)^2}$$

$$d = \sqrt[3]{0.000000468} = 0.0078\, m$$

$$d = 0.01m$$

8 Taper Screw Auger Design

Taper screw auger was obtained using equation 9 given by Lower *et al.* (1994)

$$\text{CFTHR} = \frac{(D^2 - d^2)\, P_a \;x\, N_s}{215 \; X \; 10^{-4}} \quad (9)$$

Where:

CFTHR = Material being moved by a full auger, m^3/h
D = Diameter of the screw, m

D = Diameter of the shaft, m
P_a = Pitch of the auger, usually the same as D, m
N_s = Speed of the shaft, rpm. (350 rpm) (Murumkar *et al.*, 2016)

$$CFTHR = \frac{(0.2)^2 - (0.01)^2 \ x\ 0.2\ x\ 350}{215\ X\ 10^{-4}}$$

$$= \frac{(0.04 - 0.0001)\ x\ 70}{215\ X\ 10^{-4}}$$

$$= \frac{2.793}{215\ X\ 10^{-4}} = 12990.7\ m^3/h$$

8.1 Design of Slicing Chamber Thickness

Slicing chamber thickness was obtained using equation 10 and 11 given by Khurmi (2009)

$$t = \frac{P\ X\ d}{2\sigma t1 l X\eta} \quad (10)$$

$$P = \frac{F}{A} \quad (11)$$

Where:

t = Thickness of the cylindrical shell, mm
P = Intensity of internal pressure, mPa
d = Internal diameter of the cylindrical shell, mm
$\sigma t1$ = Circumferential or hoop stress of the material of the of the cylindrical shell, = 16mPa.
l = Length of the cylindrical shell, mm
η = Efficiency of the joint (%) = 0.85
F = Force on slicing chamber, N
A = Area of slicing chamber, mm^2

$$A = \frac{\pi d^2}{4}$$

$$A = \frac{3.142\ (10^2)}{4} = 78.6 mm^2$$

$$P = \frac{20}{78.6}$$

$P = 0.25 N/mm^2 = 0.25MPa.$

$$t = \frac{0.25\ X\ 200}{2\ X\ 16\ X\ 1.2\ X\ 0.85}$$

$$t = \frac{50}{32.64} = 1.5mm$$

Say 2.5mm

8.2 Design of Knife Thickness

Knife thickness was obtained using equation 12 given by Khurmi (2009)

$$t = \frac{P\ X\ d}{2\sigma t} \quad (12)$$

Where:
t = Knife thickness, mm
P = Intensity of internal pressure, mPa
d = Diameter of Turmeric, mm = 25 mm (Murumkar *et al.*, 2016)
σt = Circumferential or hoop stress of the material to be cut, mPa = 665mPa

A = Area of Turmeric, mm^2 = 49.8 mm^2 (Murumkar *et al*., 2016)
F = Force required to cut Turmeric, N = 107N (Murumkar *et al*., 2016)

$$P = \frac{107}{0.395}$$

P = 270N/mm^2
P = 270mPa

$$t = \frac{270 X 25}{2 X 665}$$

t = 5.1 mm
Say 6 mm.

Figure.1 below shows the diagram of the machine.

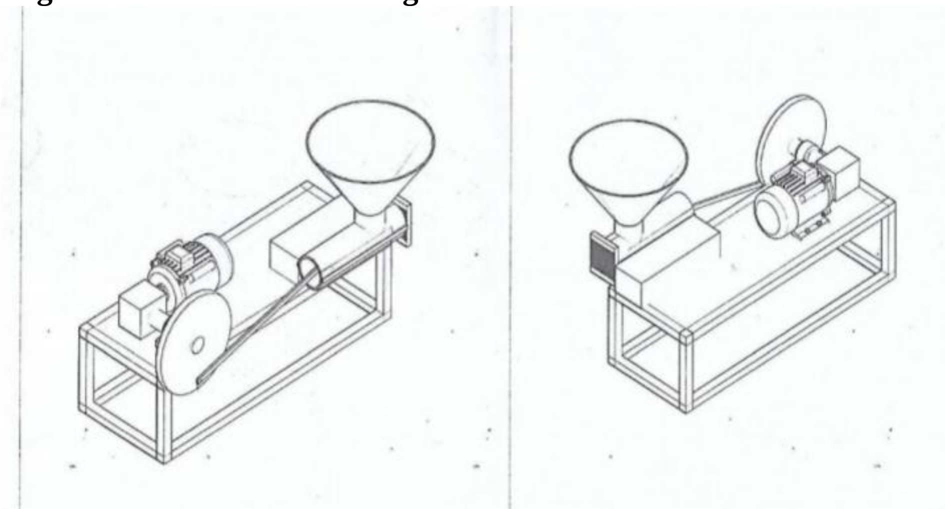


Figure 1: Turmeric machine.

Test procedure

Some Turmeric rhizomes were purchased from Sabo market in Ikorodu, Lagos, Nigeria. The samples were sorted and cleaned. Nine (9) samples were weighed and each sample was fed into the machine through the hopper at a constant low feed rate. The fed materials were pushed by the piston into the cylinder against the stationary blade and were sliced into the desired thickness. The slicing was longitudinal. Whole slices and damaged slices were separated and weighed. Three replicates were made. The weights of the samples were varied and time taken to slice to predetermine weight was recorded. The machine capacity was calculated using equation 13.

$$\text{Machine capacity} = \frac{\text{weight of turmeric (output, kg)}}{\text{time taken (hr)}} \quad (13)$$

The sliced turmeric were collected and weighed to determine material loss. The loss occurred due to the compressive force generated by the reciprocating piston with the stationary blade. To determine the slicing efficiency, the fully sliced and the sliced pieces were separated and weighted accordingly. The material loss and slicing efficiency were calculated using equations 14 and 15 given by Gupta and Khurmi (2004)

$$\text{Material loss (\%)} = \frac{Qin - Qout}{Qin} \times 100 \quad (14)$$

$$\text{Slicing efficiency (\%)} = \frac{Qout - Qbroken}{Qout} x\ 100 \quad (15)$$

Where:
Q_{in} = weight of turmeric fed into the machine
Q_{out} = weight of turmeric collected at outlet
Q_{broken} = weight of non-uniform slice turmeric

Results and discussions

Results

The results obtained during the test are as shown in Tables 1, 2 and 3, respectively and the machine performance was calculated from parameters gotten from the results.

Table 1: Weight of uniform and non-uniform slice, and efficiency of sliced turmeric for 1kg

Weight Of Turmeric Collected (kg)	Time of Operation (Hr)	Weight of Uniform sliced Turmeric (kg)	Weight of Non-Uniform sliced Turmeric (kg)	Slicing Efficiency (%)	Non-Uniform slice (%)	Material Loss (%)	Machine Capacity (kg/hr)
0.95	0.0272	0.60	0.35	63.20	36.80	5.00	34.90
0.93	0.0283	0.62	0.31	59.70	40.30	7.00	32.60
0.87	0.0288	0.60	0.27	68.90	31.10	13.00	30.20
Average				63.9	36.1	7.30	32.60

Table 2: Weight of uniform and non-uniform slice, and efficiency of sliced turmeric for 2kg

Weight Of Turmeric Collected (kg)	Time of Operation (Hr)	Weight of Uniform sliced Turmeric (kg)	Weight of Non-Uniform sliced Turmeric (kg)	Slicing Efficiency (%)	Non-Uniform slice (%)	Material Loss (%)	Machine Capacity (kg/hr)
1.97	0.060	1.23	0.74	62.40	37.60	3.00	32.80
1.95	0.0561	1.10	0.85	56.40	43.60	5.00	34.80
1.93	0.0589	1.13	0.80	58.60	41.40	7.00	32.80
Average				59.13	40.9	5.00	33.50

Table 3: Weight of uniform and non-uniform slice, and efficiency of sliced turmeric for 3kg

Weight Of Turmeric Collected (kg)	Time of Operation (Hr)	Weight of Uniform sliced Turmeric (kg)	Weight of Non-Uniform sliced Turmeric (kg)	Slicing Efficiency (%)	Non-Uniform slice (%)	Material Loss (%)	Machine Capacity (kg/hr)
2.92	0.0828	1.67	1.25	57.20	42.80	8.00	35.30
2.94	0.0794	1.65	1.29	56.10	43.90	6.00	37.00
2.93	0.0772	1.63	1.30	55.60	44.40	7.00	38.00
Average				56.30	43.70	7.00	36.80

Overall uniform slicing efficiency = $\frac{\text{total average of slice}}{\text{number of average slice}} x\ 100$ (16)

Overall Slicing efficiency = 59.8%
Overall percentage of non-uniform slices = 40.2%
Overall machine capacity = 34.3 kg/hr

Discussion

From the table, the slicer has an overall slicing efficiency of 59.8%, while the throughput and the percentage of non-uniformity slices are 34.3 kg/h and 40.2% respectively. These parameters were tested with three different weights (1 kg, 2 kg and 3 kg) at three replicates each. It was observed that turmeric of low quantity has higher slicing efficiency than that of high quantity. For instance, turmeric of 1 kg, 2 kg and 3 kg weight have the average slicing efficiency of 63.9%, 59.13%, 56.30% respectively. This could be due to reduction in quantity of turmeric in the cylinder which the piston pushed against the stationary blade. High percentage of non-uniform slicing efficiency was observed for high quantity of turmeric fed, for example 36.1% for 1 kg and 43.7% for 3 kg. The material loss mainly occurs due to the clearance between the piston and the blade, also due to the spacing of blades. The scraped turmeric particles were collected at the inner part of the cylinder and the space between the blades. The average material loss observed from 1 kg, 2 kg and 3 kg turmeric sliced are 7.30%, 5.00% and 7.00% respectively.

Conclusion

The turmeric slicing machine was constructed and the evaluation of its performance has been carried out. The sliced turmeric was uniform in size. The machine can be used to achieve different slice of turmeric which is done by changing the blade of the slicer to that of required dimension. The obtained value shows that the overall efficiency of machine is higher due to lower speed of the machine operation and proper sharpness of stationary blade and smooth movement of the piston which increase the slicing efficiency of the machine. The machine capacity was higher compared to the labor capacity.

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