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Design and development of fresh turmeric rhizome slicer

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Abstract
This study was to develop the fresh turmeric rhizome slicer to improve the slicing efficiency of fresh turmeric rhizomes and to reduce the drying time of turmeric slices to make the turmeric powder. A fresh turmeric rhizome slicer was designed, fabricated. The developed machine was evaluated for its performance against machine capacity, slicing efficiency and material loss. The developed machine was consists machine consists of main frame, electric motor, pedestal bearing, spring loaded hopper, blade header, covering assembly, power transmission mechanism and nut and bolts. It works on the principle of shearing and cutting. The performance was carried at constant speed of 400 rpm at three various slicing thickness (3 mm, 5 mm and 7 mm) on three different days (first day, second day and third day) after polishing with their respective moisture content (84.7%, 81.75% and 81.65%). The highest machine capacity, slicing efficiency and material loss were observed for 7 mm, 3 mm and 3 mm slicing thickness and the values were found to be 130.67 kg/h, 94.07% and 2.50%, respectively.

Keywords: Development, turmeric, slicer, machine capacity, slicing efficiency, material loss

Introduction
The turmeric rhizome (*Curcuma longa* L.), is a member of the ginger family (*Zingiberaceae*). Turmeric's history is connected with the history of Indian culture and with the nation's socioreligious events. It was greatly used even in Vedic times due to its special colour and flavour properties. In Ayurveda the turmeric is used as an important medicine to cure various diseases. It has a great significance in religious ceremonies and auspicious occasions. The turmeric is also used as a spice, dye, condiments (Bhat and Hegde, 2018) [6]. India is the world's biggest producer, consumer, and exporter of turmeric. Because it contain a high amount of curcumin, Indian turmeric is regarded as the best on the global market. India produces about 80% of the world's turmeric and exports 60% of it. (Anonymous, 2020) [2]. The Konkan region also grows turmeric as an unconventional crop. Normally, turmeric rhizomes are used in the form of dried rhizomes or in the form of powder. The turmeric processing involves various unit operations include cleaning, washing, boiling, drying, polishing, grinding and packaging.

Before cooking and steaming, turmeric is frequently sliced, either for direct consumption or as a step in a processing system. Size reduction, also known as cutting or slicing of turmeric which accelerates the cooking. Without changing the chemical properties, mechanical means are used to reduce the size. The conventional method of turmeric slicing practiced by manual method. This manual methods is injurious, laborious, unhygienic, tedious, and produces uneven slice thickness. Traditional methods do not produce uniform slices, which can lead to uneven drying which causes the fungal infestation. The quality of slices are plays a very important role in drying of slices (Hoque and Saha, 2017) [9]. The manual means of turmeric slicing gives a limited output. It would therefore be desirable to develop a turmeric slicing machine that can be used by small-scale farmers, business people, and individuals. This machine should be able to slice turmeric at a precise size, quickly, sustain constant high efficiency, be safe for the user's fingers as well as be portable and reasonably priced (Tanimola *et al*. 2019) [15]. The material used for fabricating the machine which must neither be contaminate the turmeric nor be corroded itself when it comes in contact with water or moisture. Therefore the stainless steel (grade 304) material is used for fabricating the components which are directly comes in contact with the rhizomes during the slicing operation (Agbetoye and Balogun, 2009; Ezeanya and Charles, 2020) [1, 7]. So that the final sliced material will be hygienic and free from contamination.

Cutting or slicing of turmeric is necessary in order to achieve fast drying for preparation of turmeric powder. Although the mechanical slicers are available in market but these are very costly and are beyond the limit of farmers and small entrepreneurs. In India, a little research work had done on the development of turmeric slicing unit for fresh turmeric rhizomes. This research work gives the huge scope to design and development of turmeric slicing machine.

Materials and Methods

The materials used for development and method adopted for its evaluation is presented here.

Design considerations for development of fresh turmeric rhizome slicer

Development work of fresh turmeric rhizome slicer was undertaken in a view of medium output capacity and able to slice both finger rhizomes and mother rhizomes. Moisture content of polished turmeric, clearance between the hopper and blade header and speed were important parameter to achieve the high slicing efficiency of slicer machine. Following points were considered for development of fresh turmeric rhizome slicer.

1. It should be smooth in operation with low noise.
2. It should be safe and low maintenance.
3. It should be low cost machine.

Determination of various physical properties of polished turmeric rhizomes

The physical property are determined for the Salem variety of turmeric. The physical properties include axial dimensions (length, width and thickness), geometric mean diameter, sphericity, bulk density, true density and porosity (Mohsenin, 1986) [11]. To fabricate the hopper and selection of constructing material the properties like angle of repose and co-efficient of friction of static friction was determined (Gayathri *et al*. 2016) [8].

Design calculations

1. Spring loaded hopper

Volume of hopper for 2.5 kg polished turmeric was calculated by Eq. 1.

$$V_r = \frac{Q}{\rho} \quad \ldots\ldots (1)$$

Where,
V_r = Required volume of hopper, cm^3
Q = Capacity of hopper, (2500 g)
ρ = Bulk density of polished turmeric (0.4616 g/cm^3)
V_r = 5415 cm^3

The rectangular shaped hopper was selected and the volume was calculated by Eq. 2.

$$V_o = L \times B \times H \quad \ldots\ldots (2)$$

Where,
L = length of hopper (23 cm)
B = Width of hopper (13 cm)
H = Height of hopper (16 cm)
V_o = Volume obtained (5681 cm^3)

2. Design for the power of electric motor

The power of the electric motor was calculated according to Khurmi and Gupta, (2005) [10].

Torque of blade header was calculated by using Eq. 3.

$$T = F \times r \quad \ldots\ldots (3)$$

Where,
T = Torque of the blade header
F = Force required for the slicing the turmeric rhizomes = 0.1029 kN (Ramos *et al.* 2020) [13].
r = Radius of the blade header = 0.405m

$$P = \frac{2\pi N T}{60} \quad \ldots\ldots (4)$$

Where,
P = Power required, hp
N = number of revolution of blade header per minutes (407 rpm)
P = 1.0 hp

3. Design of main shaft for the blade header

The main shaft was subjected to combined effect of torsion loading and bending. Hence, according to the maximum stress theory (Khurmi and Gupta, 2005) [10].
Bending moment for the shaft was calculated by using Eq. 5.

$$M_{bt} = \frac{2 \times M_t}{D_t} \times X_t \quad \ldots\ldots (5)$$

Where,
M_{bt} = Bending moment, N-m
M_t = torque to be transmitted (18.20 N-m)
D_t = diameter of motor pulley (0.1778 m)
X_t = Distance of pulley from the center of bearing (0.01 m)
M_{bt} = 2.0472 N-m

The equivalent twisting moment of the shaft was calculated by using Eq. 6.

$$T_t = T_{et} = \sqrt{(K_b \times M_{bt})^2 \times (K_t \times M_t)^2} \quad \ldots\ldots (6)$$

Also

$$T_{et} = \frac{\pi \times {d_t}^3 \times \tau_t}{16} \quad \ldots\ldots (7)$$

Where,
T_{et} = Equivalent twisting moment, N-m
T_t = Torque to be transmitted, N-m
τ_t = Maximum shear stress of the shaft material (40 ×10^6 N/m^2)
K_b and K_t = Combined shock and impact factors for bending and twisting moment (1.5 and 1.0)
d_t = Diameter of the main shaft, m

$$T_e = \sqrt{(1.5 \times 2.0472)^2 \times (1.5 \times 18.20)^2} = \frac{\pi \times {d_m}^3 \times 40 \times 10^6}{16}$$

d_t = 16.17 mm ≈ 17 mm

To prevent lateral moment of the bearing and pulley with shaft surface, the shaft was progressively stepped with increment of 5 mm diameter but according to market availability, the 25 mm diameter main shaft was selected.

4. Design of belt drive

Velocity ratio of V belt drive for two pulleys was calculated by using Eq. 8. (Khurmi and Gupta 2005) [10].

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad \text{..} \quad (8)$$

Belt Length (L) was calculated by using Eq. 9.

$$L = 2C + 1.57(d_1 + d_2) + \frac{(d_2 - d_1)^2}{4C} \quad \text{......................} \quad (9)$$

Where,
L = length of belt, mm
d_1, d_2 = diameter of pulleys 1 and 2 respectively, (50.8 and 177.8 mm)
N_1, N_2 = speed of pulleys 1 and 2 respectively, (1425 and 407 rpm)
C = distance between the Centre's of two pulleys, (440 mm)
L = 1248 mm

Construction of fresh turmeric rhizome slicer

The materials used in the construction of fresh turmeric slicer machine are MS plate, MS angles, GI pipe and SS sheet. The materials were selected based on their flexibility, low density and resistance to corrosion.

1. **Main frame:** The main frame supported to the whole machine assembly including blade header, covering assembly, power transmission assembly and electric motor. It was made with M. S. angles of size 40×40×5 mm. The height of supporting frame was 75 cm from the ground. The diameter of the blade header was 405 mm and the length of hopper was 300 mm. Therefore, the size of the fabricated main frame was 500×500×750 mm.
2. **Cutting blades:** The blades were used for slicing the turmeric rhizomes. It was made up with Stainless Steel material with a dimension of 150×50×4 mm. The 15° champers were given by using the milling machine to make edges sharpened.
3. **Blade header:** It was made with 6 mm thick M. S. plate with diameter of 405 mm. It holds three blades with an angle of 120° to each other. The powder coating treatment was given to avoid the corrosion.
4. **Covering assembly:** The covering assembly for power transmission mechanism and blade header was made with the Stainless steel (Grade: 304, Gauge: 21) to avoid the corrosion.

Working of developed fresh turmeric rhizome slicer

Adjust the clearance between the main frame and blade header for precised thickness of turmeric slices. Fill the polished turmeric rhizomes in the spring loaded hopper by pulling the handle in backward direction and lock it by inserting the lock pin at the end of stopper. Due to pulling, the torsion spring gets compressed. The slicer machine was switched ON and remove the lock pin from the handle. The pressure plate pushes the turmeric rhizomes against the blade header due to the compression of torsion spring. The blade header rotated continuously at the face of hopper. When the polished turmeric rhizomes goes in contact of blade header it was slices the turmeric rhizome to precise thickness. The sliced material were collected at the outlet of slicer.

Performance evaluation of developed fresh turmeric rhizome slicer: Performance evaluation of the fresh turmeric rhizome slicer was done for three various parameters *viz.* machine capacity, slicing efficiency and material loss, described by Nagaratna *et al*. (2017) [12].

The performance evaluation of developed fresh turmeric rhizome slicer was carried out by taking 1000 gm polished turmeric at constant speed of 400 rpm for three different cutting thickness (3 mm, 5 mm and 7 mm) on three various days after polishing of turmeric (first day, second day and third day) with an average moisture content 84.70%, 81.78% and 81.65% (w.b.), respectively.

1. Machine capacity

$$\text{Machine capacity (kg/h)} = \frac{Total\ weight\ of\ turmeric\ sliced\ (kg)}{Time\ taken\ to\ slice\ the\ turmeric\ (h)} \quad \text{.....} \quad (10)$$

2. Slicing efficiency

$$\text{Slicing efficiency (\%)} = \frac{Weight\ of\ total\ quantity\ of\ turmeric\ sliced - Weight\ of\ unsliced\ turmeric}{Weight\ of\ total\ quantity\ of\ turmeric\ sliced} \times 100 \quad \text{.....} \quad (11)$$

3. Material loss

$$\text{Material loss (\%)} = \frac{Total\ weight\ of\ turmeric\ before\ slicing - Weight\ of\ turmeric\ after\ slicing\ (g)}{Total\ weight\ of\ turmeric\ before\ slicing\ (g)} \times 100 \quad \text{.....} \quad (12)$$

Results and Discussion

The physical properties of polished turmeric rhizomes were determined and are presented in Table 1. The results obtained for performance evaluation of developed fresh turmeric slicer with its CD (@ 5%) and CV were presented in Table 2.

Table 1: Physical properties of polished turmeric rhizomes

Sr. No.	Properties	Average
1	Length (mm)	55.74
2	Breadth (mm)	23.82
3	Thickness (mm)	19.91
4	Geo. mean diameter (mm)	29.26
5	Sphericity	0.53
6	Bulk density, kg/m^3	461.6
7	True density, kg/m^3	1032.12
8	Porosity, %	55.02
9	Angle of repose, °	32.97
10	Static coefficient of friction	
	Galvanized Iron surface	0.67
	Mild Steel surface	0.74
	Stainless Steel surface	0.56

These values of physical properties were used for the design calculation of hopper.

Performance evaluation of developed fresh turmeric rhizome slicer: The results obtained for performance evaluation of developed fresh turmeric rhizome slicer against machine capacity, slicing efficiency and material loss were shown in Table 2.

Table 2: Performance evaluation of developed fresh turmeric rhizome slicer

Treatment details	Average Machine capacity (kg/h)	Average Slicing efficiency (%)	Average Material loss (%)
T_1D_1	94.67	94.07	0.87
T_1D_2	103.67	93.70	2.50
T_1D_3	105.34	92.55	2.17
T_2D_1	110.67	93.20	1.30
T_2D_2	105.33	89.03	1.17
T_2D_3	103.73	90.33	1.400
T_3D_1	124.3	87.13	1.10
T_3D_2	130.67	84.70	1.13
T_3D_3	110	85.77	1.07
Anova			
Effect	Non-significant	Significant	Non-significant
CD (@ 5%)	24.02	3.43	1.39
CV (%)	12.63	2.20	60.31

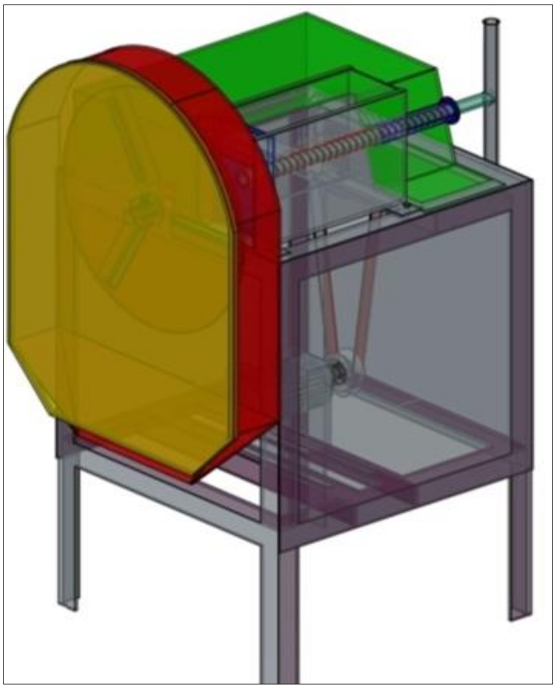

Fig 1: Design of fresh turmeric rhizome slicer

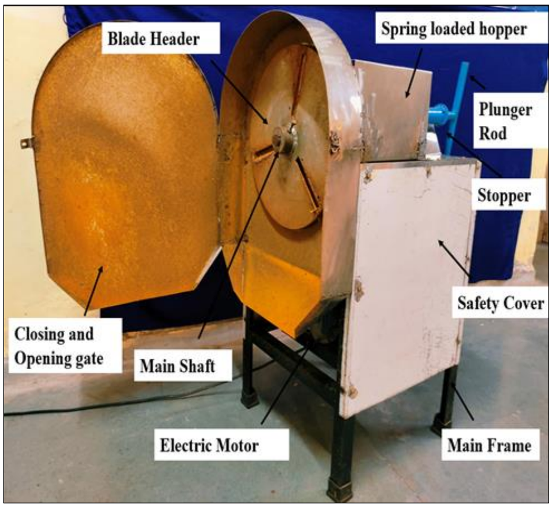

Fig 2: Developed fresh turmeric rhizome slicer with components

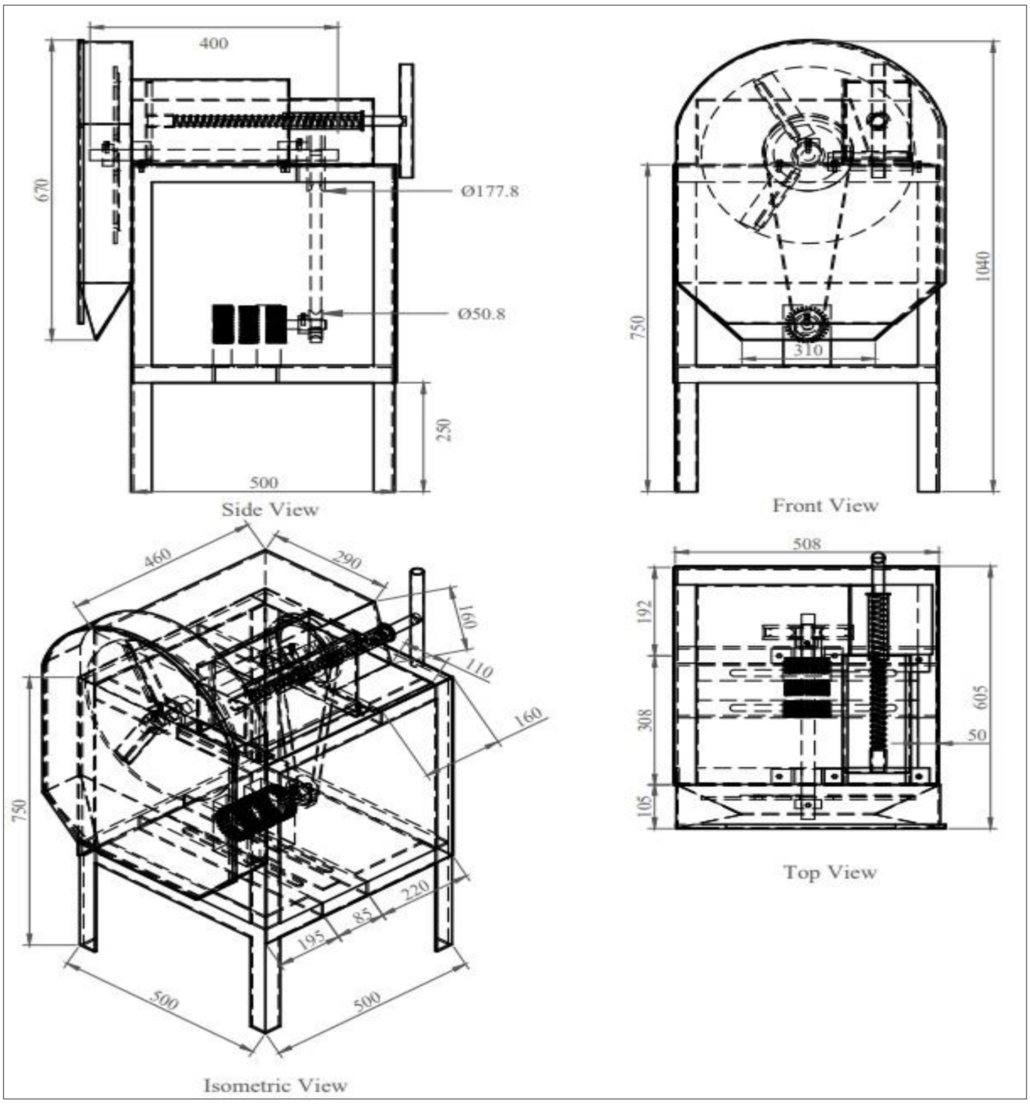

Fig 3: Details of developed fresh turmeric rhizome slicer

Machine capacity

The highest average machine capacity of 130.67 kg/h was observed for 7 mm slice thickness while lowest machine capacity of 94.67 kg/h is observed for 3 mm slice thickness respectively. The value of machine capacity increased with increase in slicing thickness from 3 mm to 7 mm from first day to third day after polishing. The time required for slicing the polished turmeric rhizomes is depends on thickness of slices to be sliced by developed slicer. For slicing of large slice thickness, less time was required and for small slice thickness the maximum time was required. These results were obtained because of number of cuts required to slice the polished turmeric rhizomes at precise thickness. For slicing the turmeric rhizome at small thickness (i.e. 3 mm slice thickness) the more number of cuts were required while for large thickness (i.e. 7 mm slice thickness) less numbers of cuts were required. It was observed that, the machine capacity is increases with increase in slice thickness and vice versa (Fig. 4).

From the ANOVA it was observed that the various treatments such as slicing thickness (3 mm, 5 mm and 7 mm) and days after polishing (first day, second day and third day) had a Non-significant effect on machine capacity of developed fresh turmeric rhizome slicer at 5% level of significance with a coefficient of variance of 12.63% and critical difference of 24.02%.

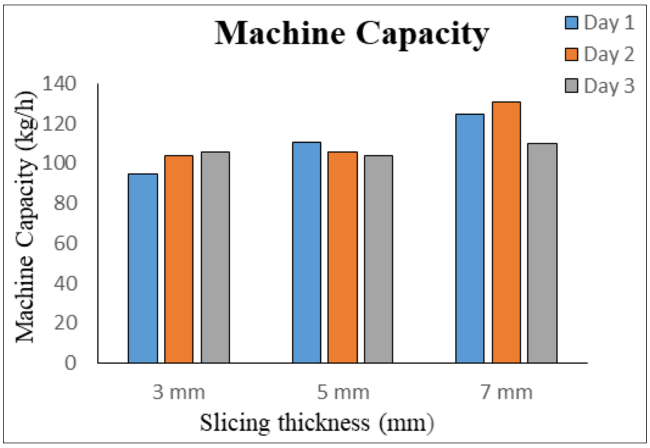

Fig 4: Machine capacity of developed fresh turmeric rhizome slicer

Slicing efficiency

The highest average slicing efficiency (94.07%) was recorded for 3 mm slice thickness and lowest average slicing efficiency (84.70%) was observed for 7 mm thickness. The slicing efficiency of the developed slicer is depends on thickness of slices to be sliced by developed fresh turmeric rhizome slicer. The thickness of slices is maintained by adjusting the clearance between blade header and main frame. It was observed that, the slicing efficiency is decreases with increase in slice thickness and vice versa (Fig. 5).

From the ANOVA it was observed that the various treatments such as slicing thickness (3 mm, 5 mm and 7 mm) and days after polishing (first day, second day and third day) had a Non-significant effect on slicing efficiency of developed fresh turmeric rhizome slicer at 5% level of significance with a coefficient of variance of 2.20% and critical difference of 3.43%.

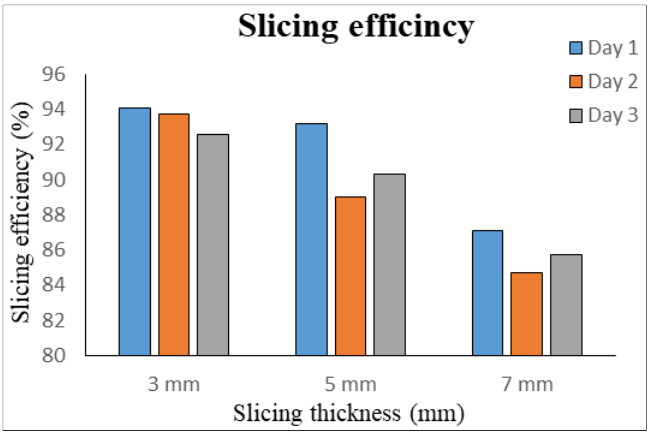

Fig 5: Slicing efficiency of developed fresh turmeric rhizome slicer

Material loss

It was observed that highest material loss is 2.50% for 3 mm slice thickness whereas the lowest material loss is 0.87% for 7 mm slice thickness. The material loss is mainly occurs due to clearance between blade header and frame, spacing between the blades. The relation between material loss and slicing thickness was shown in Fig.6.

From the ANOVA it was observed that the various treatments such as slicing thickness (3 mm, 5 mm and 7 mm) and days after polishing (first day, second day and third day) had a Non-significant effect on machine capacity of developed fresh turmeric rhizome slicer at 5% level of significance with a coefficient of variance of 60.31% and critical difference of 1.39%.

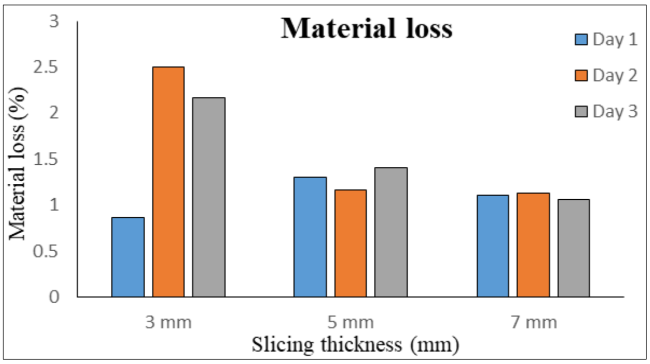

Fig 6: Material loss in developed fresh turmeric rhizome slicer

Conclusion

The developed fresh turmeric rhizome slicer successfully slices the turmeric rhizomes at desired thickness. The highest machine capacity, slicing efficiency and material loss were observed for 7 mm, 3 mm and 3 mm slicing thickness and the values were found to be 130.67 kg/h, 94.07% and 2.50%, respectively. However, the lowest machine capacity, slicing efficiency and material loss were observed for 3 mm, 7 mm and 7 mm slicing thickness and the values were found to be 94.67 kg/h, 84.70% and 0.80%, respectively. It is concluded that, the machine capacity increases with increased in slice thickness but remaining both parameters i.e. slicing efficiency and material loss were decreases with increase in slicing thickness.

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