Design and development of power operated banana slicer for small scale food processing industries

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Abstract

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A power operated rotary banana slicer suitable for small scale processing was designed and developed based on engineering properties of banana varieties, namely Nendran and Dwarf Cavendish. This banana slicer mainly consists of feeders for round slicing, cutter, power transmission mechanism, base support and frame. The power operated rotary slicer with three blade cutter that was operating at 360 rpm speed was developed to overcome drawbacks of existing hand or power operated rotary slicers and to meet the demand of small scale processing industries. This slicer has slicing efficiency of about a 93–94% with effective capacity of about 100 kg/h for both varieties. The mean thickness of cut for both varieties was about 2.00 ± 0.194 mm, whereas mean roundness was of 0.84 and 0.70 for Nendran and Dwarf Cavendish varieties respectively.

Keywords: banana; power operated slicer; round slices; effective capacity; slicing efficiency

Banana (*Musa paradisiaca*) is called as "Apple of Paradise" because it is the one of oldest cultivated fruit known to mankind; it is also the most nutritious. It is originated in hot tropical regions of south-east Asia. India ranks first in production of mango (40%) and banana (17%) of world production. India is the largest producer of banana and plantains in the world with a production of 16.82 million t from an area of 0.49 million ha. In India it accounts for 33% of total production of fruits and 12% of area under fruit crops. Cavendish is the major cultivar covering 62% of production of banana, followed by Mysore (16%), Bluggoe (6%), Nendran (Plantain 5%), Silk (4%), Pome (4%) and other (3%). The cultivation of banana is mainly distributed in states of Tamil Nadu, Maharashtra, Karnataka, Andhra Pradesh, Assam, Gujarat, Bihar, Madhya Pradesh and West Bengal. The production of banana is the highest in Tamil Nadu followed by Maharashtra, Karnataka, Andhra Pradesh, Gujarat, Madhya Pradesh, Bihar, Assam and West Bengal. The Indian average productivity is 34.3 t/ha while the highest productivity within India is in Maharashtra with productivity of 60 t/ha followed by Tamil Nadu with 53 t/ha (Anonymous 2005)

Banana is a tropical plant, requires warm humid climate. It can grow successfully at sea level to an altitude of 1,500 m. A mean temperature of 26.7°C and rainfall of 100 mm/month are satisfactory for its cultivation. Deep, well drained, friable, loamy soil with adequate organic matter is the ideal condition for its cultivation.

Table 1. Physical and mechanical properties of raw banana

No.	Properties	Banana varieties	
		Dwarf Cavendish	Nendran
1	diameter (max) (mm)	23.34	37.08
2	length (max) (mm)	137.00	194.50
3	width (max) (mm)	66.50	50.00
4	average weight of single fruit (g)	97.84	201.43
5	average pulp/peel ratio	1.39	2.32
6	average specific gravity (dimensionless)	0.933	1.005
7	load required to cut (max) (N)	22.40	28.20
8	cutting load per unit width (N/mm)	0.754	0.821

Banana provides a well balanced diet compared to any other fruits and satisfies the definition of good food i.e. which is easily digested and absorbed in our body. It is one of the most popular fruit of India, which is relatively inexpensive staple food. It is consumed both as ripe fruit and raw fruit and in the processed form. Banana processed products such as wafers/chips are gaining wide popularity in our day-to-day life. There is tremendous scope of banana processing unit to flourish further with increased acceptance of snack foods. The technology of banana chips making was developed by Central Food Technological Research Institute (CFTRI), Mysore, India and suggested that two varieties Nendran and Dwarf Cavendish are good for making chips (Fig. 1). Round slices are nothing but transverse sections through the peeled banana.

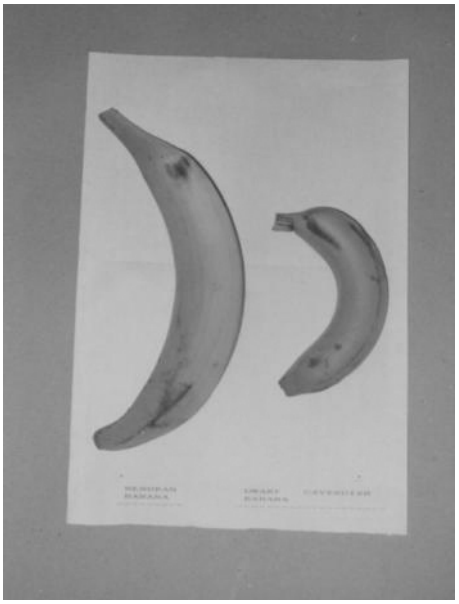


Fig. 1a. Banana varieties for wafers (Nendran – left and Dwarf Cavendish – right variety)

More than 90% of bananas produced in the country are consumed as fresh fruit. The processing of banana and plantains is only to an extent of 2–3% (estimated). The origin of processing of banana/plantain in India can be traced back to its use as chips and panchamritham in Kerala for more than 100 years. Then, chips were used as an item of feasts and festivals and panchamritham as offerings in temples of Kerala and Tamil Nadu states. Gradually the chips became a regular snack food in Kerala and took a commercial footing during 1980's and 1990's. Now it is used as snack food in homes, fast food centers, restaurants and also as side dish and garnishes. The variety of plantain called Nendran is the most suitable for this product owing to its high carotene content, which gives the product a natural deep yellow colour. Even today it is the only processed banana product widely manufactured on commercial scale in India. Very little quantities of cooking varieties like Monthan are also used in other parts of the country for chips. An estimated

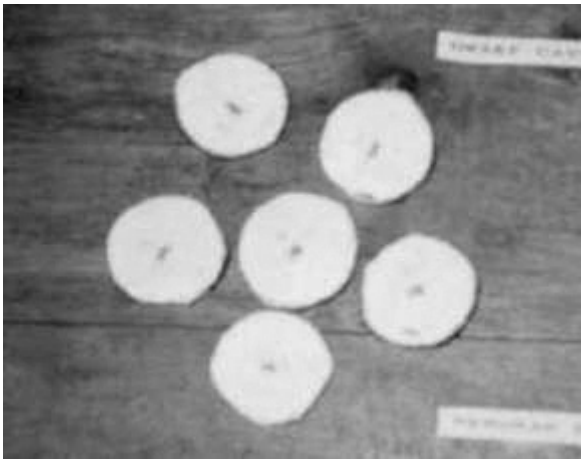


Fig. 1b. Banana round slices (transverse section of banana)

quantity of more than 100 thousand t of banana chips is produced in Kerala and Tamil Nadu per annum. It is totally under unorganized sector without any licensing. Hence it is not included in the statistics quoted above for licensed units. Major part of it goes for domestic consumption while little quantity is exported to gulf countries. Percentage wise it is estimated that processing in banana in India is to an extent of 2.5% of which approximately 1.80% is in the form of banana chips alone and the rest is in the form of panchamritham, banana flour, powder and puree. Panchamritham is used domestically in all south Indian temples; flour is used as baby food in Kerala and Northeast while powder and puree are exported. Other than processing of banana into stable products as mentioned above, substantial quantities of cooking bananas are used in India for preparation of various food items meal/breakfast/snack. Cooking bananas are used for making bajji, kofta, dry curry/koottu, podimass, etc. traditionally in India. Steamed plantain (Nendran) is breakfast food in Kerala. Ripe Nendran is used for making sweet bajji (Pazham pori) (Anonymous 2005).

Slicing is a cutting process for size reduction of fruits and vegetables; it involves pushing or forcing a thin, sharp knife to shear through the material. The result gives minimum deformation and rupture of the cell wall. Biological materials commonly subjected to cutting could be classified as:

(i) non fibrous, liquid cell materials having uniform properties in all direction at the time cutting;
(ii) fibrous materials with high tensile strength fibers oriented in a common direction with comparatively low strength materials holding the fibers together.

In first category, the compressive stress applied by the cutting tool to the cell will cause pressure in the cell wall at the point of contact with cutting tool. This point is subjected to:

(i) high shear stress because of the applied compressive stress in one direction;
(ii) tensile stress due to addition of bending stress at the point of indentation to the hydraulic stress;
(iii) movement of the tool in a direction parallel to its edge and perpendicular to the direction of the compressive force applied (slicing action) which can further add to the shear stress applied to the cell wall at the point of contact (Persson 1987).

CFTRI, Mysore, India (Anonymous 1993) suggested the process for making banana chips. Four major unit operations are involved in the banana chip making process namely peeling of banana, cutting into slices, frying and packaging of chips. Out of these unit operations both peeling and slicing are done manually. Nendran and Dwarf Cavendish are two important varieties suitable for making the wafers. The raw bananas are washed, peeled and sliced. The slices thus obtained are dipped into 2% brine solution to check the browning effect. The turmeric powder is sometimes used for colouring the banana chips.

The slices are deep fried in vegetable oils and then cooled to room temperature followed by packaging in suitable packages for further storage or transportation. Using hand operated platform type or rotary type slicer by most of the entrepreneurs presently does the slicing of the peeled banana. However some entrepreneurs' still use traditional household knives. These equipments pose danger to operators finger by inflicting the injury while slicing. These equipments produce slices of non-uniform size, shape, thickness and also produce chips of poor end quality after frying. This methods are labour-consuming and cumbersome in operation.

Researchers had put their effort in developing rotary banana slicer but yet no such machine was developed to meet the requirements of small scale processing industries.

Bhongirwar et al. (1994) reported that the power operated continuous ripened/raw banana slicer and hand operated ripened banana slicer developed at Bhabha Atomic Research Centre (BARC), Mumbai, India for commercial purpose.

Kacharu et al. (1995) studied the physical and mechanical properties of two varieties of green banana fruit viz. Nendran and Dwarf Cavendish. They reported certain important engineering properties of Nendran and Dwarf Cavendish such as average diameter, average length, average width, pulp/peel ratio, load required to cut and cutting load per unit width etc. The weight of fruit, volume and specific gravity were also determined. The average values of physical and mechanical properties presented in Table 1 were considered for design and development of this banana slicer.

Kacharu et al. (1995) reported that the power operated raw banana slicer with three blades are mounted on the rotary cutter at 120° angle. This slicer was also developed at Central Institute of Agricultural Engineering, Bhopal, India. However these slicers lacking in the provision for slicing the banana directly over the frying pan.

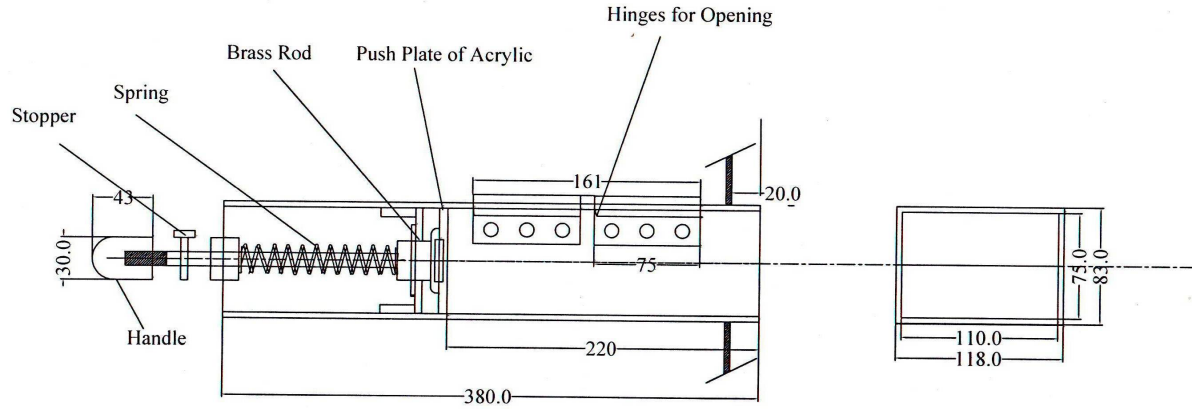


Fig 2. Dimensional details of the feeder for round slicing (mm)

The power operated rotary slicer was designed and developed to meet the demands of small-scale industries. Therefore the present research work was undertaken with the objectives to overcome most of the drawbacks of the existing slicers; new banana slicer was designed and developed and its performance was evaluated at the Aspee Research Institute, Mumbai, India.

MATERIAL AND METHODS

Design of a banana slicer requires the basic information such as engineering properties of the green banana or required capacity of machine. As per the market survey conducted, the capacity requirement of small scale banana chip manufactures is about 80–100 kg/h. Therefore to cater the need of manufacture the capacity chosen is 100 kg/h.

Development of banana slicer:

Based on the basic engineering properties of banana, a power operated rotary banana slicer was designed and developed. A brief description of its components is given below.

(i) Feeder assembly: It constitutes the feeding chute, push plate, push plate attachment, push rod and springs. A 110 × 75 mm and 200 × 55 mm cross-sectional area of the feeder was selected for round and longitudinal slice, respectively, by considering the maximum effective width and diameter of the peeled banana; 6–9 bananas can be accommodated at a time in feeder in order to get machine capacity in the range of 100 kg/h. The length of the feeding chute was taken as 350 mm for providing sufficient space for feeding banana from the top and fixing the push plate attachment with spring. The length of push rod was taken as 230 mm, which is

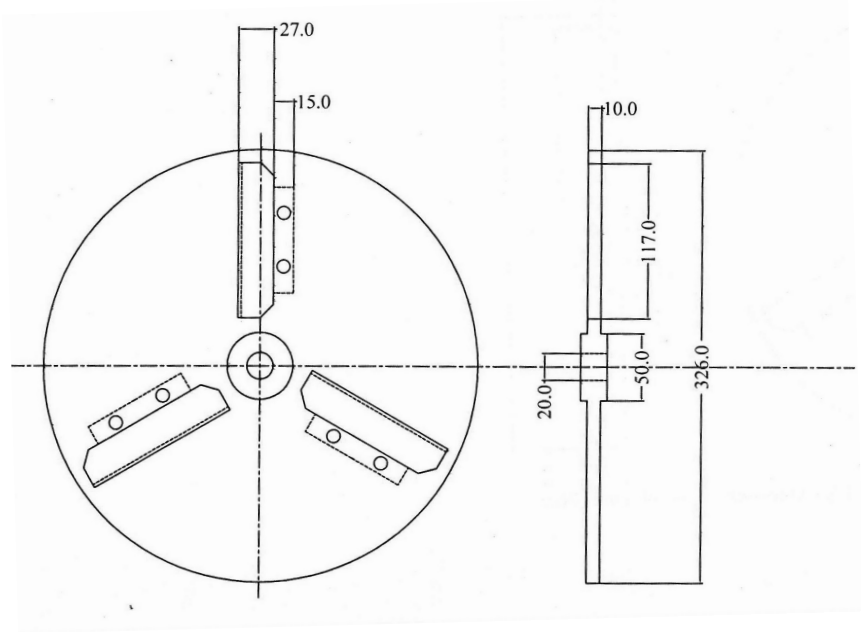
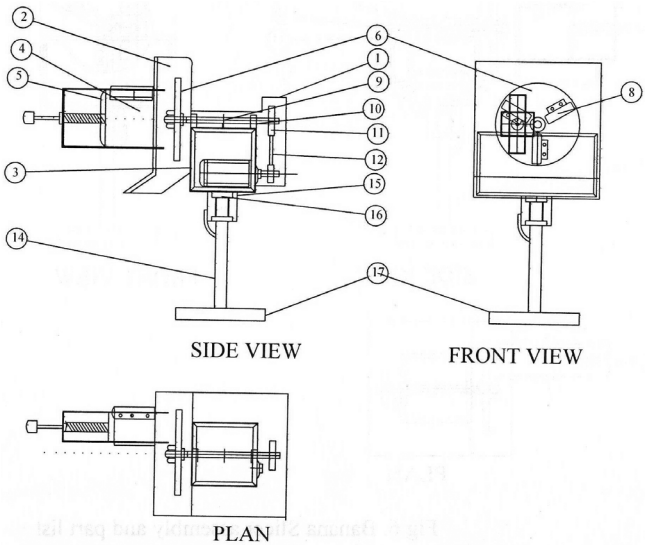


Fig. 3. Dimensional details of the cutter plate



Part list

Sr. No.	Description	Material	No.
1.	frame cover	mild steel sheet	1
2.	cutter housing and its shutter	mild steel plate	1
3.	frame	mild steel angle	1
4.	feeder box	aluminum	1
5.	push plate attachment	aluminum	1
6.	push plate	acrylic	1
7.	cutter plate	mild steel	1
8.	blades	SS410	3
9.	cutter shaft	mild steel	1
10.	pedestral bearings	–	2
11.	pulleys	cast iron	2
12.	belt (A-type)	synthetic rubber	1
13.	electric motor	–	1
14.	vertical shaft	mild steel	1
15.	bearing block	mild steel	1
16.	ball bearings	–	2
17.	foundation block	cast iron	1

Fig. 4. Banana slicer assembly and part list

equal to the distance between the push plate and open end of the feeder. The dimensional details of feeder assembly for round slicing of banana are shown in Fig 2.

(ii) Cutter assembly: Cutter assembly comprises of a cutter plate, blades and ledger plates. The blades are made up of Stainless steel (SS 410) from hygienic point view. The blade length was the basis of design of the cutter plate. The length of blade was kept as 115 mm. The thickness of blade was kept as 3 mm and calculated by considering cutting load and yield stress of material. The total energy stored in cutter plate is computed and 5.00 mm thickness of cutter plate was suggested. The dimensional details of cutter assembly with three blade disc cutter are shown in Fig 3.

(iii) Power transmission assembly: The power was transmitted from motor to cutter plate shaft by means of a synthetic rubber A-type

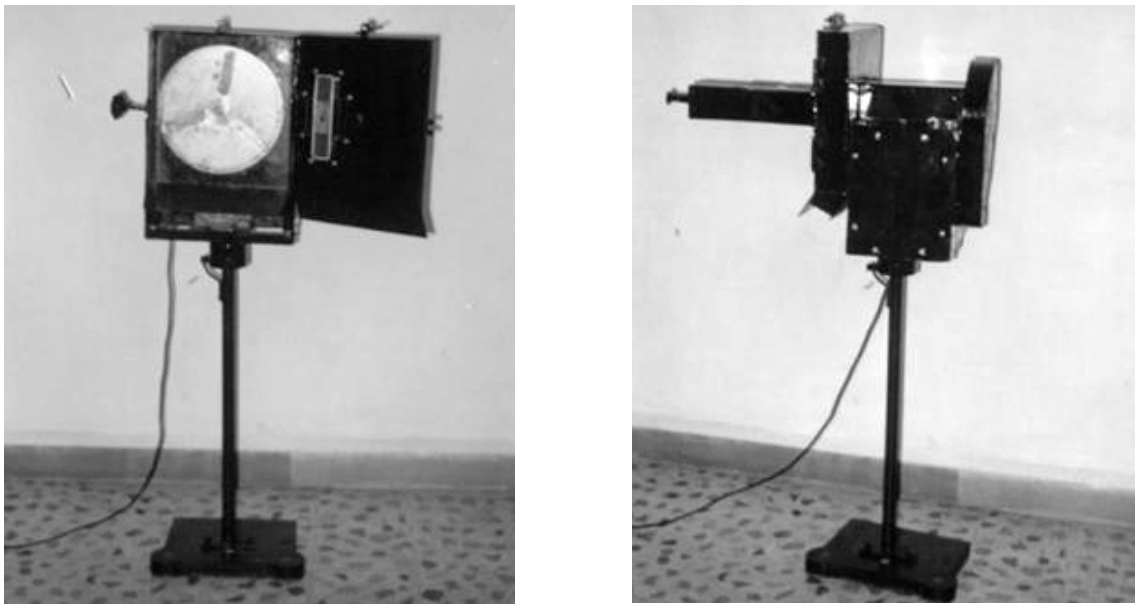


Fig. 5. Banana slicing machine (a) front view; (b) side view

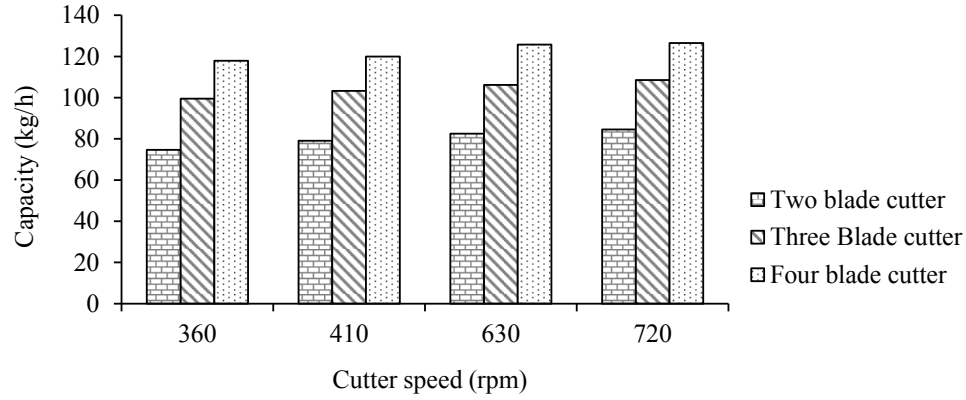


Fig. 6. Effect of number of blades and cutter speed on capacity of machine (Nendran variety)

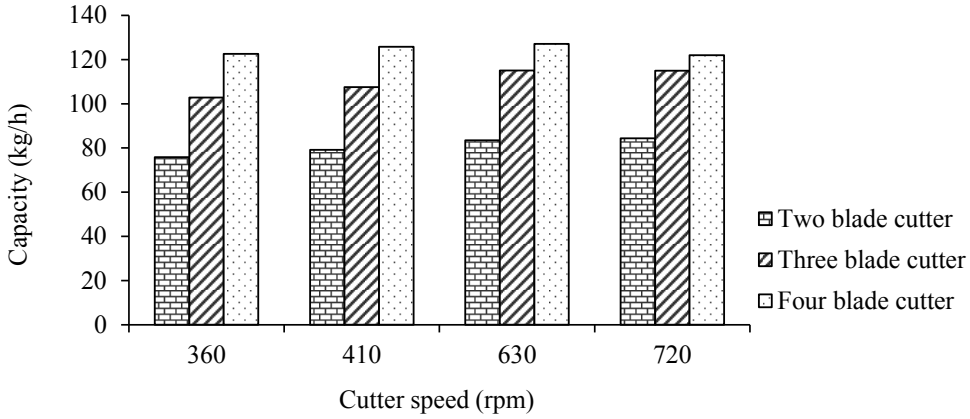


Fig. 7. Effect of number of blades and cutter speed on capacity of machine (Dwart Cavendish variety)

V belt and pulleys. The torque of cutter plate shaft was calculated considering the energy required for cutting the banana. The size of pulley was computed from the torque produced at the shaft.

(iv) Prime mover: The banana slicer is power by 0.373 kW single phase, electric motor.

(v) Frame: The machine is made sturdy while light in weight by using suitable sizes of angle. The slicer has the frame of 400 × 320 × 250 mm size, fabricated from 32 × 32 × 3.2 mm Mild Steel MS section. These sections are joined by gas welding. The pedestal bearings, cutter plate shaft, housing cover and prime mover are mounted on this frame. All these accessories were mounted with the help of fasteners.

(vi) Base support to the slicer: The 900 mm high vertical shaft provide to keep the machine at suitable height so as the feeding of banana were made easy. The diameter of V shaft was kept 40 mm determined by taking into consideration of total weight of machine (35 kg) and elastic strength of material used for shaft. The frame was mounted on shaft by means of ball bearing so as the machine was rotating in horizontal plane through right angle (90°). Thus the proposed machine is performing well in small-scale banana processing unit. The orthographic projection with part list of the developed power operated banana slicer for oblong or longitudinal slicing is presented in Figs 4 and 5.

Performance evaluation of banana slicer

Banana slicer was tested with two varieties, which are used for chip making, Dwarf Cavendish and Nendran, as shown in Fig 1. This slicer produces slices of round shape. The machine performance was evaluated with regards to the capacity, roundness index, efficiency of slicing, slice thickness etc.

The capacity of the machine was determined by feeding peeled banana into the machine and weighing the slices produced irrespective of damage. The capacity of machines is expressed as kg of peeled banana sliced per unit time. Breakage percentage is defined as the ratio of weight of damaged slices to the total weight of slices. The damaged or broken slices are defined as the slices having the area less than 2/3 of its circumscribing circle.

Slicing efficiency is the inverse term of breaking percentage. The efficiency of slicing was determined by following expression (Balasubramaniam et al. 1993).

$$\alpha = \frac{W_T - W_D}{W_T} \times 100 \quad (1)$$

where:

α – slicing efficiency (%)

W_T – weight of total slices (kg)

W_D – weight of damaged slices (kg)

Roundness index is a measure of sharpness of irregularly shaped material. Roundness index of each slice was determined by using.

$$R = \frac{A_p}{A_c} \quad (2)$$

where:

R – roundness index (fraction)

A_p – projected area of a slice (mm^2)

A_c – area of the smallest circumscribed circle of the slice (mm^2)

The laboratory test set up consists of the ammeter and voltmeter to measure the input power to motor, a tachometer, mechanical weighing balance, stop watch, planimeter, graph papers etc.

RESULTS AND DISCUSSIONS

The power operated banana slicer was evaluated for its performance on the basis of its capacity, slicing efficiency (breakage), power consumption with and without load machine and quality parameters of slices.

The banana slicers were tested for two banana varieties using three cutters (two, three and four blades) at four levels of cutter speed (360, 410, 530, 720 rpm) and for 10°, 12° and 15° bevel/edge angles of blades to study the dependent (variables) parameters. The average capacity of the developed banana slicer was observed to be about 100 kg/h when operated by three-blade cutter at 360 rpm. It was also observed that the effective capacity of banana slicer increased with an increase in number of blades at all operating speeds. Similarly as the rpm of cutter plate was increased there was an increase in the effective capacity of the slicer. The effects of different speeds of operation on the effective capacity of slicer at 2, 3 and 4 blade cutter for both varieties are presented in Figs 6 and 7.

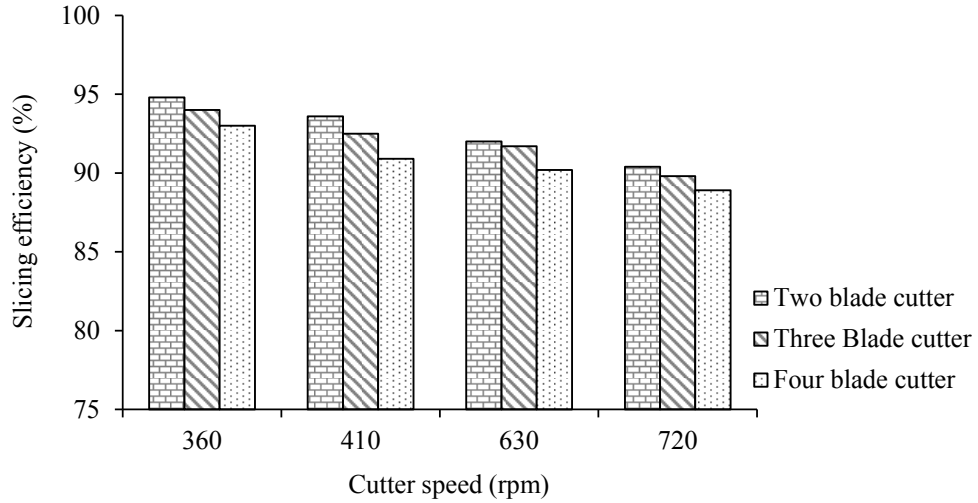


Fig. 8. Effect of number of blades and cutter speed on slicing efficiency of machine (Nendran variety)

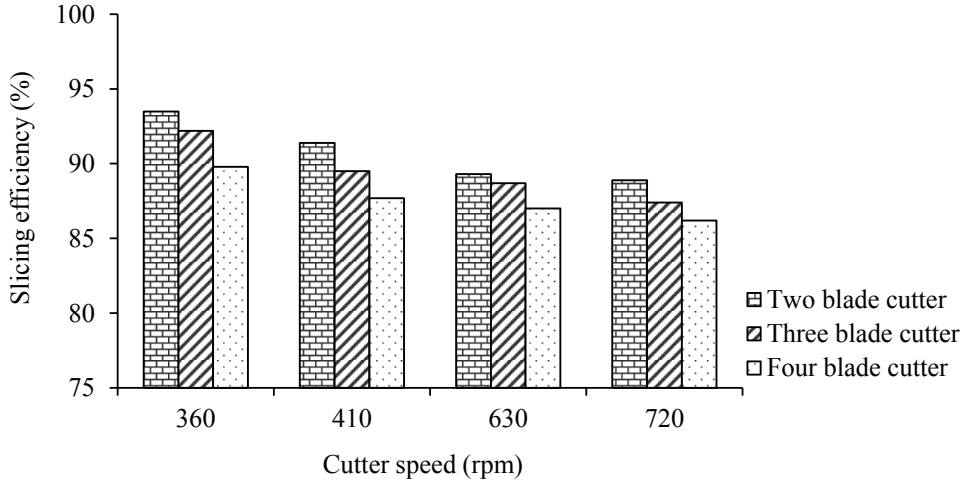


Fig. 9. Effect of number of blades and cutter speed on slicing efficiency of machine (Dwarf Cavendish variety)

Table 2. Bill of material used for fabrication of developed banana slicer

No.	Description	Material	Size expressed (mm)	Total weight (kg)	Rate (USD)	Total cost (USD)
1.	frame cover	MS sheet	320 × 250 × 1 320 × 250 × 1 400 × 320 × 1 500 × 250 × 1		1.20/kg	3.60
2.	cutter housing and its shutter	MS plate	480 × 400 × 3.25 400 × 400 × 3.25 1,360 × 30 × 3.25	10	1.30/kg	13.00
3.	frame	MS angle	32 × 32 × 3.2 of 4 m length	8	0.80/kg	6.40
4.	feeder box	aluminum	370 × 350 × 3.25 120 × 80 × 3.35 120 × 80 × 3.35	1.0	3.40/kg	3.40
5.	push plate attachment	aluminum	70 × 70 × 15	0.20	3.00/kg	0.60
6.	cutter plate	MS	330 × 330 × 15	3	1.30/kg	3.90
7.	push plate	acrylic	109 × 74 × 3.25	0.20	4.00/kg	0.80
8.	blade	SS 410	460 × 28 × 3.25	0.40	4.80	1.80
9.	ledger plate (for supporting blade)	brass	90 × 90 × 5.0	0.50	4.00/kg	2.00
10.	cutter shaft	MS	ϕ 20; length 420	1.0	1.20/kg	1.20
11.	pedestal bearing (two No.)	–	ID 20	–	2.50/piece	5.00
12.	pulleys (two No.)	cast iron	ϕ 63, 328	–	–	4.50
13.	belt (A-type)	synthetic	length 940	–	–	1.50
14.	electric motor	–	0.373 kW	–		60.00
15.	vertical shaft	MS	ϕ 40, length 1,000	3.0	1.20/kg	3.60
16.	bearing block	MS	OD 108, ID 35, length 150	1.0	1.20/kg	1.20
17.	ball bearings (two No.)	–	ϕ 30, 35		3.50/piece	7.00
18.	foundation block	cast iron	450 × 300 × 100			4.00
19.	miscellaneous (includes fastener, welding rods, brazing rods)	–				10.00
Total material cost (USD)						133.50

MS – mild steel; ID – inner diameter; OD – outer diameter

Total cost of banana slicer: (a) Cost of material: USD 133.50; (b) Cost of labour: USD 20.00 (one labour for 100 h; USD 0.20/h); (c) Machinery overhead: USD 30.00 (including electricity)

Production cost of machine = A + B + C = 133.50 + 20.00 + 30.00 = USD 183.50; Total cost of machine = production cost of machine + profit margin (25%) = USD 133.50 + USD 46.00 = USD 229.50 (say USD 230.00); Total cost of developed banana slicer = USD 230.00

The slicing efficiency of the developed rotary slicer was found between 88% and 95% for Nendran varieties while for Dwarf Cavendish variety it was between 86% and 94% for all cutting speeds and number of blades. The slicing efficiency of the slicer decreased with an increase in rpm of cutter at all the levels of number of blades. The effects of different levels of speed of cutter having two, three and four blades on slicing efficiency are presented in Figs 8 and 9 slicing efficiency of slicer is statistically analyzed. The slicing efficiency was found to be maximum at cutting speed of 360 rpm using three-blade cutter. Number of blades of cutter is significantly affecting the slicing efficiency at 5% level of significance. Therefore three-blade cutter with 360 rpm of cutter plate is best and recommended for banana slicer for round slicing. Power required to run the machine under no load condition at 10° bevel angle is 210.4 W, while

to run the machine with feed (load) it is 277.6 W. The actual power required for slicing operation was 67.2 W. The power efficiency of machine was estimated to be 32% only because power required for running machine ideally is more.

The slices were cut with average roundness of 70% and 83% for Dwarf Cavendish and Nendran varieties, respectively. The statistical analysis of data revealed that the slice roundness for both banana varieties were significantly homogenous at 5% level of significance. Nendran variety gave rounder chips than the Dwarf Cavendish. The mean thickness of the cut slices was 2.10 mm and 1.82 mm using three blade cutter, respectively, for Nendran and Dwarf Cavendish variety with the maximum deviation of thickness of banana slices is only ±0.194 mm, i.e. ±0.2 mm. The frequency analysis of date show that 95% of slices had thickness ranging between 1.7 mm and 2.5 mm for Nendran variety and 1.5 mm and 2.0 mm for Dwarf Cavendish variety. These thicknesses are preferred for making banana chips. The overall cost of developed power operated banana slicer was around USD 230.00 (Table 2). Therefore this developed banana slicer is economical and efficient for small scale food processing industries.

CONCLUSIONS

(1) The power operated rotary raw banana slicer was designed and developed. With the chosen machine speed of 360 rpm, the slicing efficiency obtained was 93–94%; it was acceptable for both varieties with optimum capacity 100 kg/h for three-blade cutter, which meets the requirements of small scale processing unit.

(2) The best chip geometry was obtained at moderate speed of machine; the slicer gives better results with average roundness of 0.84 and 0.70 for Nendran and Dwarf Cavendish, respectively.

(3) Slice thickness affects chip quality; it was found to be significantly uniform for both varieties with maximum deviation of ±0.2 mm.

(4) The overall cost of developed power operated banana slicer was around USD 230.00. Therefore the developed banana slicer is more economical and efficient than other slicers.

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