Design, development and performance evaluation of elephant apple core cutter

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Abstract In this study a hand operated elephant apple cutter was developed and the machine parameters (capacity, machine efficiency, and loss percentage, etc.) were studied. The cost and performance of the designed cutter was compared to that of the traditional cutter. The comparative performance evaluation of the designed cutter with that of traditional method indicates that the cutter offered higher sepal yield ($82.73 \pm 1.5\%$) and capacity ($100\text{--}120 \text{ kg h}^{-1}$) than the traditional cutter offered sepal yield ($63.01 \pm 3.34\%$) and capacity ($12\text{--}15 \text{ kg h}^{-1}$) with uniform coring of the finished product. The cutter could process around 235–240 number of fruits against around 30–35 by traditional in a time period of 1 h. Core cutter can be used by the farmers or rural entrepreneurs for elephant apple processing and value addition for commercial and therapeutic applications.

Keywords Design · Elephant apple · Core cutter · Cutter capacity · Sepal yield

Introduction

Elephant apple (*Dillenia indica* L.) is an underutilized fruit largely available in the sub-himalayan tract from Garhwal to Northeastern part of India, Nepal, Bangladesh and Sri Lanka (Nayak et al. 2016). The plant has great medicinal value including antimicrobial (Nazma et al. 2009), antioxidant (Arbianti et al. 2007; Deepa and Jena 2011) analgesic (Badrul et al. 2012), anti-inflammatory (Yeshwante et al. 2009) and antidiabetic (Kumar et al. 2011) activities. Fruit is globose with accrescent calyx, 12.5–15 cm in diameter, aggregate of 15 carpels with large fleshy sepals tightly enclosing the true fruit. There are 5 closely fitted sepals enclosing numerous seeds embedded in a glutinous juice (Gopalan et al. 1999).

Cutting of an elephant apple fruit is not only difficult but is also a time consuming affair. It is not very popular as a fresh fruit for table purpose due to this particular criterion. It has been an age-long traditional practice by the people that the fruit is manually cut by knife. It takes about 10–15 min per fruit depending on the skills of a person cutting the fruit. The fruit is hard and thick layered for which the knife must be ensured of sharpened edged. Since the fruit is layered with five closely fitted imbricate sepals, it is to be removed one by one thereby indulging more time, labour and loss. Further, there is a possibility for the operator to be subjected to injury. Inadequate or improper cutting of elephant apple may cause problems in other processing stages such as separation of central core from the fruits. It is therefore, important to cut elephant apples properly in order to facilitate the removal of core from fruit with minimum loss. The traditional cutting method of elephant apple is very slow and time consuming. Consequently the quantity of fruits, a farmer can process is limited (Onyemelukwe 1991). So there is a need to design a cutter for elephant apple to increase cutting speed and

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capacity. As elephant apple is a complex hard fruit with irregular shape and size, sharpness of the cutter is to be designed in a way such that it is able to cut fruits of all sizes with minimum loss.

Based on this, in this study a hand operated elephant apple core cutter was developed and performance of the designed cutter in terms of cutting time, capacity and sepal yield (Khurmi 1990; Onu and Okafor 2003).

Materials and methods

Elephant apple fruits (100 nos.) were collected from a single tree near Central Institute of Technology (CIT), Kokrajhar, Assam, India and were kept under controlled temperature (25°–30 °C) and humidity (50–55%) for at least 04 h before the trials.

Fabrication

To meet safety of operation and hygienic quality of the final product, the selection of material plays an important role in fabrication of machines. In the design of elephant apple cutter some parts may come in direct contact with the fruit. So those parts have been fabricated with stainless steel and other parts can be furnished with mild steel. Fruits are acidic in nature, so it may react with metal or mild steel leading to corrosion through which hazardous materials may be migrated into food. So, the cutter die, fruit platform, fruit holder have been fabricated with stainless steel. The details of materials and its dimensions for the fabrication of different parts of elephant cutter have been given in Table 1.

Fabrication was carried out through the standard procedure such as marking, cutting, welding, grinding, finishing and coloring etc. Selected material for fabrication was marked according to the conceptual design using electronic metal cutter. The cutter die edge was sharpened using lathe and grinding machine. Joints (Tee, corner) were welded using electric arc. The finishing of joints were made using angle grinder metal cutter.

Parts of the elephant apple cutter

The different parts of elephant apple cutter are fruit platform, cutter die, fruit holder (ring), handle, and frame as shown in the Fig. 1. Each part has been explained in the following sections. The layout was developed using AutoCAD 2008 software.

Fruit platform

The fruit platform is a component of the cutter on which fruit is positioned (Fig. 1, Part f). It acts as the base support

Table 1 Details of material selected for fabrication of elephant apple cutter

S. no.	Particulars	Material
1	Pipe	Stainless steel
2	Square pipe (25 mm)	Stainless steel
3	Pipe (12.7 mm)	MS
4	Pipe (25 mm)	MS
5	Pipe (30 mm)	MS
6	Rod (12.5 mm)	Stainless steel
7	I-angle bar	MS
8	L-angle bar	MS
9	Handle	MS
10	Plain sheet	Stainless steel
11	Nut bolt	MS
12	Color	N/A

Component of cutter	Material type	Cutter dimensions (mm)
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Dimensions of elephant apple cutter

Cutter die	Stainless steel pipe	110 × 50, 110 × 40
Frame	Stainless steel	300 × 190
Fruit holder	Stainless steel	90
Fruit platform	Stainless steel	90
Handle	Mild steel pipe	270

Fig. 1 Diagrammatic views of parts of core cutter

for other parts of the machine. The platform was made in form of a rectangular box using angle iron and stainless steel plate (Obayopo et al. 2014). Elephant apple is ellipsoidal in shape for which it does not rest well without support. So, the component has been designed with stainless steel and a ring is fitted to it where the fruit is placed. The platform is designed in such a way that it holds the fruit firmly during cutting (Fig. 1).

Core cutter

Cutter die is the major component of the fruit cutter. It is designed for the purpose of removing the central core from the sepal part of the fruit it is closely attached with imbricate sepals (Akubuo and Odigboh 1999). Cutter die consists of a serrated hollow cylinder which has the sharp edges at one end. These sharp edges remove the core part from the upper portion of the fruit. It is also made up of stainless steel. Two core cutters have been fabricated. The size of each cutter has been designed based on the physical properties of the elephant apple (Nayak et al. 2016). Both the cutters are each of 15 cm long but of different diameters (5 and 4 cm) and made to be removable to allow for change in size to match the fruit sizes (Fig. 1, Part a).

Fruit holder

Fruit holder is to serve the purpose of holding the fruit during the operation when the cutter die is moved upwards after separating the core part. During this operation, there is a possibility of fruit adherence to the cutter die. This may cause the fruit to be lifted along with the die. In order to prevent this action, fruit holder is fitted with the shaft. (Figure 1, Part b).

Handle

A handle (lever) is attached to the core cutter which is made up of a mild steel rod/pipe (Fig. 1, Part e). Initially, handle of three different lengths were designed. Based on ease of operation, comfortness and mobility, the handle length was fixed as 70 cm. This was also found ergonomically suitable. The diameter of the handle has been fixed based on comfort, strength, and security of grip. For better grip, the handle end has been provided with some grove type arrangement. Overall handle design is in a way such that it offers the desired force to operate the instrument.

Operating principle

The elephant apple cutter consists of fruit platform, fruit cutter die, fruit holder, handle and frame. Two holder rings are placed in the instrument, one of them on the platform and another one which is an adjustable one is placed above the platform at a defined distance. The purpose of placing two holder rings is to avoid the slipping of fruit as well as to avoid the upward movement of fruit during the operation. A movable fruit cutter die is placed on the upper side of the cutter, supported through two shafts which are attached to the platform. A force distribution handle (lever mechanism) is attached to the cutter die which is a hand operated one. This handle design in such an orientation

where relationships of hand forces relative to the hand and arm anatomical structures can provide critical information for determining the forces and stresses acting on the muscles, joints, and bones of the hand-wrist-arm system (Lee et al. 2008). When the fruit is placed in between the two holder rings, the fruit cutter die moves downward with the help of the shaft to bore into the fruit. When the fruit cutter dies moves upwards, it carries away the core part of the fruit. After this process, the remaining sepal part of the fruit can be separated and sliced easily and processed further for making a number of value added products.

Performance indices

Performance indices such as cutting time, cutter capacity and sepal yield were evaluated through ten experimental trials. The detailed procedure for evaluation of each performance index has been explained in the following sections. The experimental design for performance evaluation of the machine is given below.

Speed of cutting

Cutting time was determined by recording the time required to cut 5 batches, each with 10 nos of elephant apple fruits. A stop watch was used for this purpose. The speed of cutting was determined by counting the number of fruits processed per hour.

Cutter capacity

The capacity of the machine was determined by measuring the mass of fruits processed and the time of operation (Behera and Rayaguru 2016). Numerically capacity of the cutter is expressed as kg of elephant apples processed per hour and given by

$$Q = \frac{W}{T} \times 60 \quad (1)$$

where, Q = Cutter capacity, kg/h, W = Total mass of fruits, kg, T = Operating time, min.

Sepal yield (SY %)

Sepal yield is defined as the ratio of mass of sepals to total mass of whole fruit and is expressed in percentage (Behera and Rayaguru 2016). Sepal yield was calculated using following equation:

$$\text{SY, \%} = \frac{W_2}{W_1} \times 100 \quad (2)$$

where, W_1 = Total mass of whole fruits, kg, W_2 = Total mass of sepals, kg.

Statistical analysis

Trials were carried out in triplicate and Statistical evaluations of the different experiments were performed by means of SPSS software (trial version 19.0) and Microsoft excel 2010 (Snedecor and Cochran 1967). Analysis of variance (ANOVA) was applied to test the performance of the cutter for both the methods.

Results and discussion

Cutter design dimension and fabrication

Based on the conceptual design and physical properties of fruit, the dimensions of cutter and its components were decided as given in Table 1. The conceptual design drawing and dimensions along with the different views of elephant apple cutter are presented in Fig. 2. The fabricated cutter was used for experimental trials and the performance of the cutter was evaluated which is discussed below.

Performance evaluation

Experimental trials were carried out for evaluating the performance of the cutter. The results of the performance parameters such as cutting time, speed of cutting, cutter capacity and sepal yield are presented in Tables 2 and 3 (Fig. 3).

The average time required for cutting a batch of 10 elephant apples by traditional method was 1153 ± 74.55 s whereas the designed cutter takes only 151 ± 8.96 s. This was about 1/8 times that of the traditional one. Lower value of standard deviation in cutting time for designed cutter indicated a less variation in the cutting speed. From the results it is inferred that the traditional method is not only a time consuming but also a less uniform process (Hirano 1985).

From Table 3 it can be observed that the speed of cutting in the traditional cutter and designed cutter was about 8 times higher than the traditional cutting process. The cutter capacity of the designed cutter was found to be higher ($100\text{--}120 \text{ kg hr}^{-1}$) than the traditional cutter

Fig. 2 Details specification of cutter

Table 2 Performance evaluations for 5 batches (Average values of 10 fruits)

Batch	Traditional cutter					Designed cutter				
	Cutting time (s)	Mass of fruit (g)	Mass of sepals (g)	Sepal yield (%)	Mass of pulp (g)	Cutting time (s)	Mass of fruit (g)	Mass of sepals (g)	Sepal yield (%)	Mass of pulp (g)
1	1149	4382	2787	63.601	1595	150	4648	3818	82.143	822
2	1128	4454	2956	66.367	1627	141	4726	3942	83.411	778
3	1049	4398	2684	61.028	1582	162	4528	3848	84.982	674
4	1190	4285	2820	65.811	1492	159	4682	3796	81.076	851
5	1250	4512	2634	58.378	1644	145	4620	3792	82.078	814
Average	1153.2	4406.2	2776.2	63.007	1588	151.4	4640.8	3839.2	82.727	787.8
Total	5766	22,031	13,881	63.007	7940	757	23,204	19,196	82.727	3939
SD	74.55	84.88	125.5834384	3.348531425	59.07199	8.961026727	74.439237	61.62142485	1.503366952	68.732816

Table 3 Comparison of performance indices traditional and designed cutter

	Traditional cutter	Designed cutter
Speed of cutting (fruit h ⁻¹)	30–35	235–240
Cutter capacity (kg h ⁻¹)	12–15	100–120
Sepal yield (%)	63.01 ± 3.34	82.73 ± 1.5

(13–15 kg hr⁻¹). However, the percentage variation in the standard deviation from the average value in the batch wise capacity of traditional and designed cutter method did not show any appreciable differences (6.5 and 7.01% respectively).

The total recovery (sepal and pulp/central core) was found to be 99.05 and 99.7%, respectively for traditional and designed cutter method indicating higher invisible loss (0.95%) by traditional method than designed cutter method (0.3%) only. This invisible loss was occurred due to spilling of gummy substances due to injury to the florets of central core. In the experiment, the total recovery has been divided into two categories. One part is the usable component i.e. sepal and rest part is the central core which also contains the smaller fractions of sepals. Standard deviation for sepal recovery was 125.58 and 61.62 for traditional and designed cutter respectively indicating larger variation among the batches in traditional processing methods. The quantity of sepal recovered from 50 fruits (5 batches) through traditional method was 13,881 g (63.01 ± 3.34%) and that by designed cutter method was 82.73 ± 1.5% (Table 2). This indicated a higher amount of usable parts of the fruits was lost along with central core by the traditional method. This may be due to uniform and accurate coring of the fruits by designed cutter leading to less loss (Hirano 1985). Since this parameter has significance in commercial application of value-added products, the cutter can have

important contribution in preparation of finished product with intact sepals. The results are accordance with the egusi fruit pulp coring by Akubuo and Odigboh (1999).

From the single-factor analysis of variance (ANOVA), it was evident that the difference between cutting time for traditional and designed cutter method was significant ($F_{cal}889.87 > F_{tab} 5.31$) at an error level of 1 per cent. Further, the analysis of variance for percentage sepal yield, indicated that the sepal yield was significantly higher ($F_{cal}144.04 > F_{tab} 5.31$) by cutter method ($p < 0.01$) than traditional method. This was due to the fact that during machine cutting, there was no cutting of edges of the overlapping sepals due to uniform coring. On the contrary, the traditional method was dependent on the skill of the operator the cutting was based on eye estimation to extract the sepals of the fruit through edges of fruit, and, therefore, a higher loss was inevitable.

Cost analysis

Cost estimation plays an important role to determine the buying capacity of the user and profit to the manufacturer. The cost of operation of machine was divided under two heads known as fixed cost and variable cost. Fixed cost includes depreciation cost, Interest and Insurance cost while variable cost includes operator cost and maintenance cost. The expenditure for designing the instrument includes material cost and process cost. Material cost is the total cost incurred for the purchase of raw material. The process cost for a machine part comprises fabrication cost, labor charges and factory services (Obayopo et al. 2014). The detailed materials for fabrication of the components and estimated cost for elephant apple cutter is presented in the supplementary table S.1. In this design, for operating cost of machine, the life of cutter was considered as 5 years, with an annual use of 1000 h (Patil et al. 2015). The cost of

Fig. 3 Views of the final designed cutter and its evaluation

operation of machine per hour was found to be Rs. 100 for designed cutter while cost of processing per fruit is Rs. 0.11 (Supplementary Table S2). The operating cost of the designed cutter was also compared with manual cutter. The operating cost of manually cutter was Rs. 100 per hours, while cost of processing per fruit is Rs. 3.19. This indicated that the operating cost of designed cutter is much higher than the manual cutter.

Conclusion

The cutter was designed keeping in view the farmer's requirement, locally available material and ease of operation. The overall analysis of the experimental observations showed that the performance indices of the designed cutter were better than that of the traditional cutting. The designed cutter offers higher cutting sepal yield ($82.73 \pm \%$), capacity ($100\text{--}120 \text{ kg hr}^{-1}$) with more uniform coring of the finished product against those of $63.01 \pm 3.34\%$ and $13\text{--}15 \text{ kg h}^{-1}$ by traditional method. The device is of low cost with simple mechanism. It is easy to operate and can be fabricated from materials that are available locally. The cost analysis showed that the remarkable saving of Rs. 72.33 per hours in the designed elephant apple cutter is economically better than manually operated cutter. This will be suitable for use in India especially in north-eastern part, where mechanized elephant apple cutter is not available. It can be used by the farmers or rural entrepreneurs for elephant apple processing in order to enable them to go for value addition for commercial and therapeutic applications.

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