

**MODIFICATION, DEVELOPMENT AND PERFORMANCE
EVALUATION OF CUSTARD APPLE (*Annona squamosa* L.)
PULP-FLAKES EXTRACTOR**

by

Bhadle Nilesh Ganesh

(Reg. No. 2016/09)



**DEPARTMENT OF AGRICULTURAL PROCESS ENGINEERING
DR. ANNASAHEB SHINDE COLLEGE OF AGRICULTURAL ENGINEERING AND
TECHNOLOGY
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST-AHMEDNAGAR
MAHARASHTRA, INDIA**

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A Thesis submitted to the
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In partial fulfillment of the requirements for the degree
of

MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)

in

PROCESS AND FOOD ENGINEERING



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DIST. AHMEDNAGAR, M. S. (INDIA)**

2018

Dedication

Affectionately Dedicated to

Parents,

Teachers, Farmers and well wishers

..... Mr. Bhadle Nilesi Ganesh

CANDIDATE'S DECLARATION

I hereby declare that this thesis or any part
there of has not been submitted
by me or any other person to any
other University or Institute
for a Degree or
Diploma.

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Dated: / / 20

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Maharashtra State (India)

CERTIFICATE

This is to certify that the thesis entitled “**MODIFICATION, DEVELOPMENT AND PERFORMANCE EVALUATION OF CUSTARD APPLE (*Annona squamosa* L.) PULP-FLAKES EXTRACTOR**” submitted to Faculty of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (M.S.) in the partial fulfillment of the requirement for the award of degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **PROCESS AND FOOD ENGINEERING**, embodies the results of a piece of bonafide research work carried out by **MR. BHADLE NILESH GANESH** under my guidance and supervision and that no part of thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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(**Bhadle Nilesh Ganesh**)

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	:	Description
Agril.	:	Agricultural
Avg.	:	Average
Anon	:	Anonymous
C	:	Clearance
cal	:	Calorie
cc	:	Cubic centimeter
Cm	:	Centimeter
Cv.	:	Cultivar
C.D.	:	Critical difference
Co.	:	Company
cP	:	Centipoises
Dept.	:	Department
Dist.	:	District
Dr. A. S.	:	Doctor Annasaheb Shinde
Engg.	:	Engineering
<i>et al.</i>	:	and others
Er.	:	Engineering
etc	:	Etcetera
Fig.	:	Figure
FCRD	:	Factorial Completely randomized design
g	:	Gram
ha	:	Hectare(s)
Hort.	:	Horticulture
HP	:	Horse power
h	:	Hour(s)

ID	:	Inner diameter
i.e.	:	That is
IS	:	INDIAN Standards
ISA	:	Indian Standards Angle
J	:	Journal
kg	:	kilogram
kg/h	:	kilo gram per hour
kg/m ³	:	kilo gram per meter cube
kJ	:	kilo-joule
lb	:	pound
LLDPE	:	Linear Low density polyethylene
Ltd.	:	Limited
mg.	:	Milligram
m.c. or M.C.	:	Moisture content
mm	:	Millimeter
mL	:	Milliliter
M.Tech.	:	Master of Technology
mm ²	:	Millimeter square
MPKV	:	Mahatma Phule Krishi Vidyapeeth
M. S.	:	Maharashtra State
M.Sc.	:	Master of Science
m/s	:	Meter per second
Min.	:	Minute(s)
MT	:	Metric tonnes
No.	:	Number
OD	:	Outer diameter
Dr. PDKV	:	Dr. Panjabrao Deshmukh Krishi Vidyapeeth

Pub.	:	Publication
RPM/rpm	:	Revolution per minuet
Sci.	:	Science
Sr. No.	:	Serial number
Tech.	:	Technology
T	:	Tonne(s)
T/ha	:	Tonne(s) per hecter
US	:	United State
<i>viz.</i>	:	Namely
Vol.	:	Volume
Wt.	:	Weight
°C	:	Degree Celsious
°	:	Degree
%	:	Per cent
Φ	:	Phi
θ°	:	Theta degree
”	:	Inches

ABSTRACT

**Modification, Development and Performance Evaluation of Custard Apple
(*Annona Squamosa* L.) Pulp-Flakes Extractor**

by

**Bhadle Nilesh Ganesh
Master of Technology
(Agricultural Engineering)**

in

Process and Food Engineering

Mahatma Phule Krishi Vidyapeeth, Rahuri,

Dist – Ahmednagar (Maharashtra)

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Research Guide : Er. A. P. Patil**Department : Agricultural Process Engineering**

The present research titled ‘Modification, Development and Performance Evaluation of Custard Apple (*Annona Squamosa* L.) Pulp-Flakes Extractor’ has been conducted in three experiments carried out during period of 2016 to 2018. The objectives of research were to the study the engineering properties of custard apple, modify/develop custard apple pulp-flakes extractor and performance evaluation of custard apple pulp-flakes extractor.

The physical and physico-morphological properties of uniformly selected twenty five custard apple fruits of Cv. Local were observed. The average length, breadth, thickness, size and sphericity of custard apple fruits were found to be 84.68 mm, 77.86 mm, 71.05 mm, 77.66 mm and 0.92, respectively. The average peel, carpellary pulp, gritty pulp and seeds were found to be 42.56 per cent, 36.74 per cent, 12.87 per cent and 7.92 per cent, respectively. The average weight of fruit and seed was 251.78 g and 0.33 g, respectively. Physical properties of randomly selected fifty custard apple seeds were observed. The average respective length, breadth and thickness of custard apple seeds found to be 14.58 mm, 7.73mm and 5.22 mm of a fresh seeds. Further, average seed size and average sphericity arrived at 8.35 mm and 0.58, respectively. Bulk density, true density and porosity of seeds found to be 648.28 kg/m³, 898.19 kg/m³ and 27.81 per cent, respectively.

Result indicated that the angle of repose value for custard apple seed was 15.28°. The angle of repose of custard apple seeds with flakes and custard apple pulp/flakes was 36.05° and 45.77°, respectively while bulk density of custard apple seeds with flakes was 876.25 kg/m³. The rheological properties of custard apple seeds with flakes were also measured. The shearing force

required for separating flakes from the seeds, pulp stickiness and viscosity of pulp was 2.71 N, 240.40 g and 50.65 cP, respectively.

The machine was modified using different engineering properties. The modification and development of custard apple pulp-flakes extractor also considered other factors such as convenience, experience, judgment, ease, simplicity of machining and availability of material. Considerable thrust was laid on precision, accuracy and ease of operation of the machine. The method of trial and error was also used while designing the machine. The machine consists of constructional parts such as feeding hopper, central wire mounted roller with shaft, outer perforated casing, housing with seeds/pulp flakes outlet, seed outlet, pulp-flakes outlet, A.C. induction motor drive with gear box and frame on which all the parts were assembled.

Developed machine was evaluated for its efficiency in terms of core recovery, working capacity, flakes recovery and seed separation, with respect to roller speed and angle of inclination. Core recovery and working capacity found to be increased with increase in roller speed and angle of inclination. Maximum core recovery of 87.57 per cent was found for roller speed of 90 rpm and angle of inclination of 40°.

Minimum working capacity of 31.61 kg/h was recorded at speed of 30 rpm and 20° angle of inclination while maximum of 102 kg/h was recorded for roller speed of 90 rpm and 40° angle of inclination. It was observed that with increase in roller speed and angle of inclination, working capacity increased. Seed separation efficiency decreased with increase in inclination angle of drum and roller speed. Seed separation efficiency of 86.86 per cent was found at 20° angle and 30 rpm while it decreased to 83.33 per cent at an inclination angle of 30° and 70 rpm.

Flakes recovery increased with increase in inclination angle of drum and decreased with increase in speed of the roller. Maximum flakes recovery of 81.05 per cent was found for a roller speed of 30 rpm and 30° angle of inclination whereas minimum flakes recovery of 64.80 per cent was for a speed of 90 rpm and 20° angle of inclination angle of drum.

Optimum values of core recovery, working capacity, seed separation efficiency and flakes recovery was 85 per cent, 80 kg/h, 86 per cent and 75 per cent, respectively, for 65 rpm of roller and 38° inclination angle of drum.

1. INTRODUCTION

Custard apple (*Annona squamosa* L.) is one of the important fruit crops of India popularly known as *Sitaphal* or *Sharifa*. *Annona* is a genus of tropical fruit trees belonging to the family Annonaceae. Amongst 119 notified species, seven are straight cultivars, one hybrid grown for commercial use, five species have been notified as important but under-utilized. Further, three are commercially cultivable and have become popular as *Annona cherimola* (cherimoya), *Annona muricata* (soursop, guanabana) and *Annona squamosa* (sweetsop, sugar apple).

Custard apple is hardy crop which can be grown on marginal land with minimum inputs (Rathore, 1985). The shape of the fruit ranges from irregular to spherical, oblong, cordate or conical depending upon the cultivar characteristics (Thakur and Singh, 1966). The most of custard apple varieties are reddish (e.g. *Red Sitaphal*) or yellowish (e.g. Mammoth) (Thakur and Singh, 1966 and Beerh *et al.*, 1983). Skin or covering of custard apple is thin but tough which usually turns yellow or brownish when ripe. Flavour of the fruit is sweet and agreeable. Beneath the thin covering, a thick creamy white layer of granular, flesh is present, which surrounds seed.

Custard apple is considered as a dessert fruit for its delicious test and nutritive value meant for table purpose. The custard apple needs tropical climate but with cooler winters. It is a popular fruit crop of tropical states of India, generally classified as semi-wild fruit. It is mostly cultivated in India, Australia, China, Israel, Cuba, Colombia, Pakistan, Philippines. In India, Custard apple is mainly grown in the states of Andhra Pradesh, Maharashtra, Tamil Nadu, Orissa, Assam, Uttar Pradesh, Bihar, Rajasthan and some parts of Central India (Morton, 1987). In Maharashtra, custard apple crop is grown on 13,470 ha with the production of 85,340 MT. It is widely distributed throughout tropics and subtropics in Maharashtra. This fruit crop is mainly grown in the districts of Beed, Dhule, Pune, Aurangabad, Nagpur and Bhandara (Anonymous, 2017).

Custard apple is delicious fruit and used when they are fully ripe. Pleasant flavor, mild aroma and sweet taste have universal acceptance. Custard apple is excellent source of Carbohydrate. Custard apple typically provides carbohydrates, minerals and proteins to the tune of 23.5%, 0.9% and 1.6% (Gopalan *et al.*, 1991). Reported composition of custard apple is moisture (73.5%), carbohydrates (23.9%), protein (1.6%), fat (0.3%), calcium (0.02%), phosphorous (0.04%) and iron (0.01%) (Venkataratnam, 1963). It is also good source of vitamin A and C. The fruit yields around 40 per cent pulp having 26.4° B total soluble solids, 5.5 pH and 0.5 per cent tannins (Najundaswamy and Mahadevan, 1993). From custard apple seeds Ancorine can be extracted which is alkaloid and has insecticidal properties.

In traditional medicines, extract of *Annona squamosa* bark and leaves is considered beneficial for ameliorating hyperthyroidism, diabetes and liver disorders. Custard apple trees remain free from insect, pest and disease and are not eaten by any animals (Purohit, 1995). According to

Naidu and Salatore (1954), the custard apple seed contains 25.5 per cent oil useful for soap and paint industries. Custard apple is used in Indian folkloric medicine to treat several diseases including cancer. The leaf decoction is given as a vermifuge. Custard apple leaves or a paste is used for treating ulcers. Unripe fruit is rich in tannin; it is dried, pulverized and employed against diarrhea and dysentery. In severe cases, the leaves, bark and green fruits are all boiled together for 5 minutes in a liter of water to make an exceedingly potent decoction (Morton, 1987). It has been found to be very useful to the brain and the nervous system.

Availability of the custard apple fruits commences from August and continues up to December notifying October and November as a peak period. The large aggregate fruits are composed of peel, pulp, seeds and weighing about 100-230 g, with a very lumpy skin. A mature tree will produce 34-45 kg of fruits per year with adequate care, (Morton, 1987). When fruit is ripe, pulp is creamy with pleasant texture and flavor. It is very sweet and slightly acidic. It is usually eaten as a dessert fruit and finds immense applications in the preparations of beverages and ice creams (Chikhalikar, 2000).

Custard apple stored at room temperature ripens within four days with a shelf life of four days. The fruits of *Annona squamosa* being soft when ripe requires careful handling during transit and marketing. Hence, storage of custard apple fruit has limitations. Like many other tropical fruits, mature custard apple fruits get chilling injury and fruit becomes hard when stored at 15°C or below (Annabelle *et al.* 2006). The freshly harvested, uniformly ripened fruits of custard apple degrades in quality when stored for prolonged period specifying little commercial importance. Climacteric and highly perishable fruits of custard apple cannot be stored for longer period. Cold storage is not promising. Fruits are sensitive to chilling. The ripe fruits can be stored for 6 weeks at 4.4°C but the skin becomes brown, black, and unattractive, ultimately results in loss of market value. Moreover, if fruit is allowed to remain on the tree for prolonged period, the pericarp splits to open facilitating deterioration (Venkatratnam, 1963). Excessive production of Custard apple leads to wastage and deterioration owing to inadequate preservation techniques.

Custard apple is highly perishable commodity and hence fruits are preserved in the form of pulp during harvesting season. It helps in better utilization of custard apple pulp and value addition. Uniformly ripened fruits are transformed into semi-processed and processed food products by using conventional methods of processing. The pulp may be consumed raw or transformed into various food products and tastes aromatic sweet, with custard like flavor. It has great potential for value addition through processing (Kotecha *et al.*, 2000).

Processed products of custard apple such as jam, jelly, crush etc. has more demand in the market if they have flakes along with pulp. The custard apple could be processed into products like jelly, jam, conserves, sherbet, syrup, tarts and fermented drinks (Khurdiya, 2001).

Custard apple is considered as a critical fruit for separating the seeds from pulp-flakes with minimum damage to the flakes. A manual separation of pulp-flakes is very time consuming, unhygienic. It also leads to crushing of flakes to some extent. Further manual separation has constraints in separation of pulp-flakes on large scale. Very little work on mechanical extraction has been reported on the development of pulping machine with minimum damage to the flakes. Presently, a brush type pulping machine is being used for the operation but by this means the flakes are crushed to large extent. Thus, there is vital need to develop a machine to extract the pulp-flakes with minimum damage to flakes.

Considering the facts of rapidly increasing area under custard apple and its minimum shelf life, there is a need to develop suitable pulper for custard apple. The present research work entitled “Modification, development and performance evaluation of custard apple pulp-flakes extractor” was therefore undertaken in the Department of Agricultural Process Engineering, Dr. A. S. College of Agricultural Engineering and Technology, M.P.K.V., Rahuri, Dist. Ahmednagar, Maharashtra, India with the following objectives:

- 1) To study the engineering properties of custard apple.
- 2) To develop and modify custard apple pulp-flakes extractor.
- 3) To evaluate performance of custard apple pulp-flakes extractor.

2. REVIEW OF LITERATURE

Custard apple (*Annona squamosa* L.) is receiving importance as a promising crop of dry land horticulture in India. However, extraction of custard apple pulp with retention of flakes and processing aspects has received adequate attention. On the relevant review of physico-morphological properties of fruits, physical properties of seeds, rheological properties of custard apple pulp, mechanical extraction of fruit pulp and design of pulping machine are discussed in this chapter.

2.1 Physico-Morphological Properties of Fruits

Thakur and Singh (1966) reported that, the shape of custard apple was cordate with 8.2 cm length, 9.5 cm diameter, 360 cm³ volume and 338.8 g weight. The colour was pale yellow with red blush and covered with grayish bloom, areoles rhomboid or serpent-head shaped, separated by faintly impressed lines.

Thakur and Singh (1966) studied the pomological description and classification of some annonas. The fruit parts of annona (side view and longitudinal view) (Fig. 2.1) and (Plate 2.1) shows rind, seed, carpel, carpellary pulp, gritty pulp, core, etc.

Khader and Jaypal (1977) showed that the weight of custard apple fruits ranges from 126 to 483 g depending upon cultivars and environmental conditions.

Beerh *et al.* (1983) reported an average fruit polar length and diameter varying from 6.6 to 9.2 cm and 7.4 to 9.1 cm, respectively in 7 cultivars of custard apple. They also reported that the fruit of Mammoth cultivar were largest in size, some weighed as much as 750 g. They showed that the portion of gritty pulp (adjacent to peel) and carpellary pulp (around the seed) ranging from 5.9 to 13.2 and 25.3 to 42.0 per cent, respectively. The content of peel and seed varied from 42.9 to 50.4 and from 3.4 to 8.4 per cent, respectively. The average seed weight ranged from 0.29 to 0.47 g in 7 cultivars of custard apple.

Dhumal (1994) reported the average length, diameter and weight of the custard apple fruits were 6.6 cm, 6.9 cm and 143g, respectively. He also observed the average number of seeds per fruit as 46 i.e. 8.1 per cent of the weight of the fruit along with 45.4 per cent peel and 46.7 per cent pulp.

Kolekar (2002) found that the average peel, seed and pulp percentage of custard apple fruits were 43, 13 and 44 per cent, respectively.

Mohite (2002) recorded the proportion of peel, seeds, pulp and process losses as 41.5, 12.0, 46.1 and 0.4 per cent, respectively for custard apple.

Silva *et al.* (2002) reported that custard apple fruit weight varied from 226 to 418 g, pulp yield varied from 45 to 54 per cent and soluble solids content varied from 26.49 to 28.02 per cent.

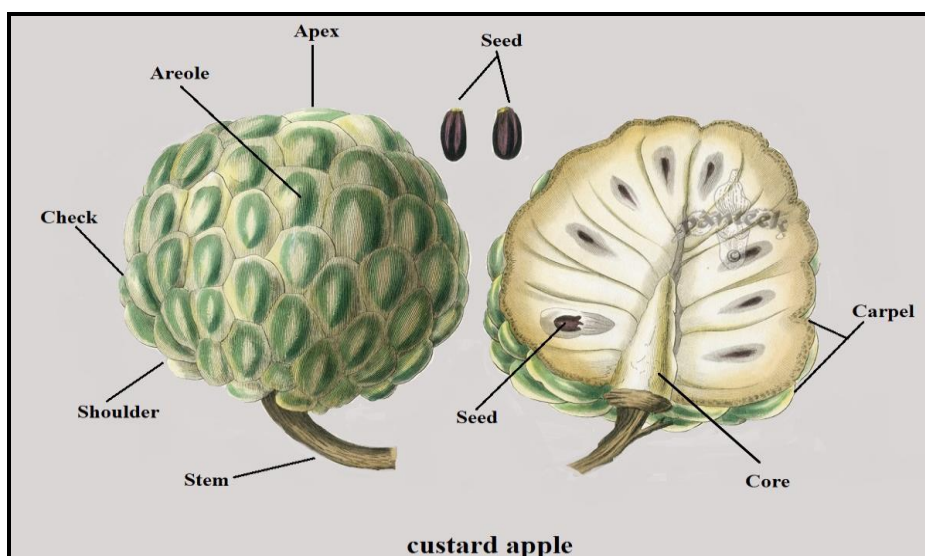


Fig. 2.1 Fruit parts of annona

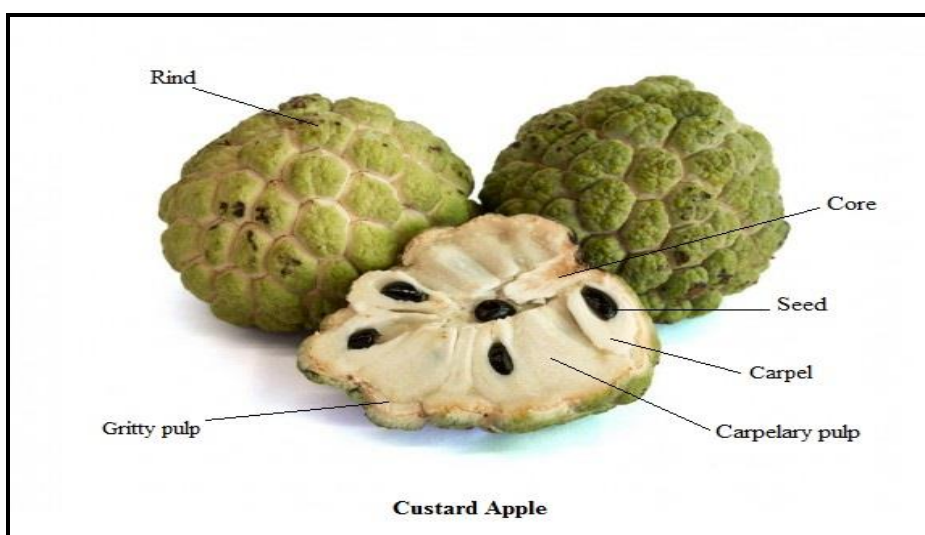


Plate 2.1 Longitudinal section of custard apple

Badhe et al. (2007) studied the physical properties of alphonso mango. The quality of mango for export was judged on the basis of size, weight, maturity, total soluble solids, acidity, specific gravity, firmness and attractive golden yellow colour on ripening. The mangoes were grouped in four grades according to weight and the physical properties like weight, volume, length, breadth, thickness, pulp, peel and stone content and physiological loss in weight were determined. The results pertaining to the fruits in export grade indicated that the average weight was 273.05 g and 241.54 g at raw and ripe stage, respectively. The volume of the fruit found as 269.61 and 221.51 cc, specific gravity 1.01 and 1.09, average length 95.97 and 94.62 mm, average breadth 77.73 and 74.20 mm and average thickness 69.54 and 65.60 mm at raw and ripe stage, respectively.

The physiological loss in weight was recorded by 10.94 per cent on ripening. The ripe fruit contains average per cent of pulp as 65.12, peel 20.14 and stone as 14.74.

Pawar (2012) measured different physical and morphological properties of custard apple fruits. The average length, width, breath, size and sphericity of custard apple fruit (Cv. Balanagar) was 77.45mm, 67.00mm, 56.32mm, 66.35mm and 0.857, respectively. The average peel, carpellary pulp, gritty pulp and seeds were found to be 49.76, 31.93, 12.13 and 6.18 per cent, respectively. The average weight of fruit and seed was 183.06 and 0.307 g, respectively.

Jadhav et al. (2015) observed the gross weight, size, arithmetic mean diameter, sphericity, surface area, seeded pulp content, deseeded pulp content, peel content, number of seeds per fruit and volume of custard apple fruit varied in the range of 154.3 to 395.9g, 6.2 to 8.9 cm, 6.3 to 9.0 cm, 0.8 to 1.0, 120.4 to 251.1 cm², 41.6 to 63.2 per cent, 36.9 to 51.7 per cent, 28.2 to 44.2 per cent, 11 to 77 and 153.0 to 411.3 cm³, respectively.

Kishan Kumar et al. (2015) investigation was carried out to find the suitability of custard apple fruits commercial cultivation on the basis of different physical characteristics such as fruit weight is 215.88 g (IGCA-21) to 290.15 g (IGCA-38).

Bakane et al. (2016) reported average weight of the fruits in the range of 105.67 to 164.00 g.

Kad et al. (2016) reported physical and morphological properties of custard apple fruits and seeds as well as rheological properties of pulp-flakes which are important for determining the unit operations during processing of custard apple pulp and for design of pulp-flakes extractor. In the present investigation, physical and morphological properties of custard apple fruit such as peel, carpellary pulp, gritty pulp and weight of seeds per fruit were found to be 46.77, 35.36, 11.63 and 6.24 %, respectively. Size, sphericity and angle of repose were found to be increased with increase in moisture content while bulk density, true density and porosity decreased with increase in moisture content of custard apple seeds.

Kad et al. (2016) observed physical and morphological properties of custard apple fruits. The average weight of fruit and seed was found to be 238.68 and 0.30 g, respectively. Peel, carpellary pulp, gritty pulp and seeds were found to be 46.77, 35.36, 11.63 and 6.24 percent, respectively. Number of seeds, total weight of pulp, fruit to pulp ratio and pulp to seed ratio were found to be 49.50, 113.29 g, 2.14 and 8.18, respectively. These results are in agreement with Beerh *et al.* (1983), Pal and Kumar (1995), Rao and Subramanyam (2011) and Pawar (2012) for physical and morphological properties of custard apple fruits. Linear dimensions of 100 randomly selected fruits *viz.*, length, breadth and thickness were recorded as 84.00, 74.25 and 65.15 mm, respectively. Size and sphericity of custard apple fruit were found to be 74.04 mm and 0.88,

respectively. These results are in accordance with Beerh *et al.*(1983), Dhumal (1994), Pal and Kumar (1995) and Pawar (2012) for the length, width, thickness, size and sphericity of custard apple fruits.

Ramesh *et al.* (2016) observe that the characters of custard apple fruit, average fruit length, breadth and weight were 10.45 cm, 12.35 cm and 264.72 g, respectively.

2.2 Physical Properties of Seeds

Very limited information has been found on physical properties of custard apple seeds. The previous studies of other commodities were referred because limited attempt was carried out for determination of the physical properties of custard apple seeds.

Thakur and Singh (1966) reported that the seeds of the custard apple were oblong in shape with length 1.12 cm and breadth of 0.68 cm. Seeds were narrow and truncated at the micropylar end but broader at the other end with testa smooth and dark brown.

Mishra and Kulkarni (2009) investigated the physical properties of the cumin seeds as a function of moisture content. Studies on rewetted cumin seeds showed that length, width, thickness, diameter of equivalent sphere and mass of 1000 seeds increased linearly with the increase in moisture content. Angle of repose was also increased from 33 to 46 degrees.

Esref Isik and Halil Unal (2011) studied some engineering (physical and mechanical) properties of white kidney bean grains (*Phaseolus vulgaris* L.) were as a function of moisture content in the range of 10.01 to 25.00 per cent dry basis (d.b.). The average length, width and thickness were 8.638, 16.747 and 4.958 mm, respectively at a moisture content of 10.01 per cent (d.b.). However, the thousand grain mass was increased from 472.5 to 696.2 g, the projected area from 128.13 to 198.83 mm², the true density from 1128.05 to 1290.85 kg-m⁻³ and the terminal velocity from 5.51 to 8.50 m-s⁻¹ in the moisture range from 10.01 to 25.01 per cent (d.b.).

Pawar (2012) calculated different physico-morphological properties of seed with respect different moisture content. The linear dimension of custard apple seeds were found to be decreased with decrease in moisture content. The size and sphericity of custard apple seeds decreased from 8.443 to 7.702 mm and 0.646 to 0.630, respectively with decrease in moisture content at three level from 15.25 to 10.00 per cent. While, the bulk density, true density and porosity of seeds was found to be increased from 645.20 to 681.81 kg/m³, 1205.8 to 1374.8 kg/m³ and 46.47 to 48.19 per cent, respectively. The angle of repose of custard apple seed decreased from 27.72 to 24.76° with decrease in moisture content from 15.25 to 10 per cent.

Kad *et al.* (2016) studied the physico-morphological properties of custard apple seeds. The respective size, sphericity, bulk density, true density, porosity and angle of repose of seeds were

found in the range of 8.828 to 8.091 mm, 0.648 to 0.625, 642.42 to 684.03 kg/m³, 898.22 to 1002.73 kg/m³, 28.46 to 31.74 per cent and 29.47 to 25.84. The size and sphericity decreased while bulk density, true density and porosity increased with decreases in moisture content of the seed from 15.40 to 10.25 per cent (d.b.) and angle of repose found to be decreased from 29.47 to 25.84°.

Ramesh *et al.* (2016) reported the seed per cent and number of seed per fruit as 5.47 and 15, respectively.

2.3 Rheological Properties of Custard Apple Pulp

Kad *et al.* (2016) reported that, rheological properties of custard apple pulp-flakes such as stickiness (184.34 g), hardness (596.67 g), cohesiveness (0.31) and viscosity (50.9 cP) were observed along with the shear force (1.84 N) required to separate the pulp-flakes from seeds. Hardness and cohesiveness of custard apple pulp was recorded as 596.67g and 0.31, respectively. Stickiness, which is the product of hardness and cohesiveness was found to be 184.34 g.

Kad *et al.* (2016) reported viscosity and torque of custard apple pulp were 50.9 cP and 33.07 Nm, respectively.

2.4 Extraction of Pulp

Maclae *et al.* (1993) reported two methods for removing custard apple pulp, a screen processing process and reaming process.

Kotecha *et al.* (1995) obtained pulp from peeled custard apple fruits by separating the seeds manually. They observed that 0.2 per cent pectinase and four hours incubation period were found to be the optimum conditions for extraction of juice from custard apple pulp.

Dhumal *et al.* (1997) undertaken an investigation to standardize the method of extraction of pulp from custard apple fruits. The pulp was extracted by hand pressing and by using screw type extractor with and without prior heating and by using pectinase enzyme. The per cent pulp, seed and peel reported were 46.3, 8.4, and 45.3 for cold screw method; 46.9, 8.2 and 45.0 for hot screw method; 46.4, 8.3, and 45.3 for cold hand press method; 46.8, 8.1, and 45.1 for hot hand press method and 46.7, 8.3 and 45.0 for enzymatic extraction method, respectively. The evaluation of pulp for chemical composition and organoleptic properties indicated that hand pressing without prior heating was the most suitable method for extraction of pulp from custard apple fruits.

Kolekar (2002) worked on the extraction of custard apple pulp by cold hand press and pulping machine and found non-significant difference in recovery of peel (43.0 and 42.5 per cent,

respectively). Recovery of seed and pulp were 13.0 and 44.0 per cent, respectively by cold hand press method while 17.5 and 40.0 per cent, respectively by pulping machine method.

Pawar (2012) worked on extraction of custard apple pulp by pulp-flakes extraction machine. The performance evaluation of pulp- flakes extractor machine were calculated for core recovery, flakes recovery, capacity with respect to different roller speed. The core recovery was found to be increasing with increasing in roller speed. Maximum and minimum core recovery of 79.45 per cent and 67.45 per cent was found for roller speed of 100 rpm and 30 rpm, respectively. It was observed that with increase in roller speed, the capacity increased but the flakes recovery decreased due to more crushing of the flakes. Hence after analysis of data an optimum roller speed of 60 rpm was found to be effective with a flakes recovery of 58.20 per cent, capacity of 35.40 kg/h and core recovery of 70.95 per cent. The flakes recovery was found to be increased but the speed separation efficiency was decreased with increased in angle of inclination. An optimum flakes recovery of 55.27 per cent and seed separation efficiency of 77.00 per cent was found at an inclination angle of 30°.

Bakane *et al.* (2015) extracted the custard apple pulp using de-seeding machine developed by Department of Agricultural Process Engineering, Dr. PDKV, Akola. It was observed that machine capacity and machine efficiency increased with increase in roller speed and feeding rate.

Kad (2015) extracted the custard apple pulp by pulp-flakes extractor. The performance evaluation of pulp- flakes extractor machine were evaluated for core recovery, working capacity, seed separation efficiency and flakes recovery in respect of roller speed and angle of inclination of drum. The core recovery increased with increasing in roller speed and angle of inclination. Maximum core recovery of 94.76 per cent was found for roller speed of 90 rpm and angle of inclination of 45 degree. The minimum working capacity of 16.54 kg/h was recorded at speed of 30 rpm and 20 degree inclination angle of drum while maximum of 60.40 kg/h was for a roller speed of 90 rpm and 45 degree inclination angle of drum. It was observed that with increase in roller speed and inclination angle of drum, the working capacity was increased. The seed separation efficiency was decreased with increase in inclination angle of drum and roller speed. A seed separation efficiency of 87.66 per cent was found at 20 degree angle and 40 rpm, while it decreased to 78.73 per cent. At an inclination angle of 45 degree and 90 rpm. The flakes recovery increased with increase in angle of inclination and decreased with increase in speed of the roller. The maximum flakes recovery of 77.88 per cent was found for a roller speed of 30 rpm and 45 degree angle of inclination whereas minimum flakes recovery of 32.23 per cent was for a speed of 90 rpm and 20 degree angle of inclination. Hence, after analysis of the data by

using response surface contours, an optimum value of core recovery, working capacity, seed separation efficiency and flakes recovery was 91 per cent, 48 kg/h, 80 per cent and 60 per cent, respectively for 77 rpm of roller and 42 degree inclination angle of drum.

2.5 Design of Pulping Machine

Dostal (1920) invented a fruit and vegetable pulping machine with the objectives to facilitate the feeding movement of the pulp from the grinding mechanism to the centrifugal separating mechanism and to increase the efficiency of the machine in terms of volume of output. The machine consists of two mechanisms, the upper grinding section provided with grinding blades on a conical surface extending radially from its centre and lower centrifugal separating mechanism consisting of central shaft, a drum wall and screen cylinder. The material comes in the annular space between drum wall and screen cylinder from the grinding section and was separated by means of centrifugal action. An important objective of this invention was to facilitate the feeding movement of the pulp from the grinding mechanism to centrifugal separating mechanism, to avoid the tendency of the material to choke at the entrance of the drum by reason of the momentum imparted to the material by the rotating action of the grinding mechanism.

Lewis (1937) invented a pulping machine for fruit with the major objective of increasing the amount of juice extracted per unit of material handled and to provide a simple machine construction and more efficient in operation. The machine consists of beater blades mounted upon spider those are in turn mounted on horizontally disposed shaft extending longitudinally through the machine. The beater blades are radially adjustable relative to the shaft and rotate within the screened drum. The edges of the drum are moving close to the inner periphery thereof to engage and squeeze the material against and through the openings in the drum thereby extracting the juice and finely divided pulp.

Lindley (1937) developed a machine for extracting juice or pulp from some fruits and vegetables. The machine consists of a smooth faced pressing drum provided with a feed blade rotating eccentrically within the outer cylindrical screen. The feed material is being squeezed in the clearance (1/16'' to 2'') between drum and screen. The rotational speed of drum at 175 rpm was found to be effective for tomato juice extraction.

Charles (1949) developed a machine for pulping fruits and vegetables with the major objective to provide unitary beater assembly in which the paddles of the beater are adjustable radially relative to pulping drum to suit the condition of the various types of material to act upon.

Catelli (1997) invented a machine for extracting juice of some fruits and vegetables from the skins or seeds. A tubular strain provided with an inlet and discharge outlet for refuse by-

products, spout has its central shaft, bearing a plurality of spatulas, each of which has an extremity set very close to a surface of strain. The tubular strain exhibits holes which are progressively or step by step diminishing in diameter inlet to outlet. He also concluded that, lesser peripheral velocities of the central shaft mounted with radial spatulas were found to be effective for separation of the pulp from seeds of various fruits with minimum stress on the outer strain.

Sale (1999) studied the performance of pomegranate seed extractor at different rotational speeds of shaft mounted with blades. He reported that, increase in shaft speed leads to increase in crushing of pomegranate seeds. He also reported that the lower shaft speed (325 rpm) gave higher seed separation efficiency (92.34 per cent) compared to higher shaft speed (440 rpm). Capacity of the machine was maximum for higher shaft speed. Maximum seed loss of 5.10 per cent was found in case of 440 rpm and minimum of 3.73 per cent for 325 rpm.

Khawaja and Muhammad (2010) developed a machine for cold pulping of tomato to isolate pulp, seed and peel from fresh tomato. They studied the effect of machine parameters such as roller surface (flat or serrated), variation in the roller clearance and rotational speed on pulping of tomato. They concluded that, greater the speed of rollers (72 rpm) had increased momentum and inertial forces than that by the lower speed (36 rpm), hence resulting in more impact action for squeezing out more pulp. They also reported that roller clearance is inversely proportional to pulp production. At smaller clearance ($C=1$ mm), greater pulp recovery was achieved than that at larger clearance ($C=2$ mm). Larger diameter of roller (26 cm) increased the contact area of rollers and tomato surface, which thus increased tomato grip during pulping, resulting in more pulp recovery than with the smaller diameter roller (18.5 cm). Serrated rollers helped in increasing the pulp recovery than plain rollers.

Pawar (2012) developed custard apple pulp-flakes extracting machine. The machine was developed to materialize the idea of retention of maximum flakes. The machine consist of construction parts such as central wire-mounted roller with shaft, outer casing, outer shell cover, feeding hopper, seed outlet, pulp-flakes outlet, drive mechanism with electrical motor and frame on which all the parts were assembled. The performance evaluation of pulp-flakes extracting machine was conducted at different roller speed (30, 40, 60, 80 and 100 rpm) and angle of inclination (20, 30 and 40 degree). The optimum pulp-flakes recovery of 55.27 per cent and seeds separation efficiency 77.00 per cent was found at an inclination angle of 30 degree and 60 rpm roller speed.

Bakane et al. (2014) developed deseeding machine for custard apple which was consist of brush roller, cylinder sieve, discharge chute, cover with feed hopper rigid frame and transmission unit.

The performance of the machine was conducted at roller speed (215, 227 and 257 RPM), feeding rate (0.2, 0.3, 0.42 and 0.6) and three cylindrical sieve (1, 2 and 3). Cylinder 2 with inlet diameter of 213 mm and outlet diameter of 177mm showed better results with machine efficiency 82.50 per cent and minimum pulp loss of 2.09 per cent among three cylinders.

Kad (2015) designed and developed custard apple pulp-flakes extractor. The machine was developed to materialize the idea of retention of maximum flakes with maximum seed separation efficiency and capacity. The machine consist of construction parts such as central wire-mounted roller with shaft, outer casing, outer shell cover, feeding hopper, seed outlet, pulp-flakes outlet, electrical motor drive with gear mechanism and frame on which all the parts were assembled. The performance evaluation of pulp-flakes extractor *viz.*, working capacity (kg/h), seed separation efficiency (%), core recovery (%) and flakes recovery (%) were conducted at different roller speed (30,40,50,60, 70, 80 and 90 rpm) and angle of inclination (20, 25,30, 35, 40 and 45°). The optimum values obtained from the machine under research regarding core recovery, working capacity, seed separation efficiency and flakes recovery were 91 per cent, 48 kg/h, 80 per cent and 60 per cent, respectively for 77 rpm of roller and 42° inclination angle of drum.

3. MATERIALS AND METHODS

This present investigation on “Modification, development and performance evaluation of custard apple (*Annona squamosa* L.) pulp-flakes extractor” was conducted at various laboratories of Agricultural Process Engineering and Post-Harvest Technology Centre, Mahatma Phule Krishi Vidyapeeth, Rahuri and M/s. Sahyadri Farmers Producer Company Ltd., Nashik. This chapter deals with the materials and experimental procedure used under the study.

3.1 Materials

3.1.1 Custard apple fruits

Uniform size and healthy fruits of custard apple Cv. Local were procured from the orchards of progressive farmers and local market of Nashik for the experiments (Plate 3.1).

3.1.2 Glassware

All the glassware used were obtained from manufacturer M/s. Borosil Glass Works Ltd. (BGWL), Ahmedabad, Gujarat.

3.1.3 Stainless steel for construction of extractor

The raw material used for construction of all contact parts of custard apple pulp-flakes extractor was food grade stainless steel-316.

3.1.4 Stainless steel square pipe

The raw material used for construction of frame of custard apple pulp-flakes extractor was square pipe of stainless steel-316.

3.2 Instruments Used in Research Work

During the research work, different instruments were used to determine various engineering properties of custard apple and performance evaluation of custard apple pulp-flakes extractor. The list of these instruments are given below in the Table 3.1. and Plate 3.5 to 3.10.

Table 3.1 Instruments used for the research work

Sr. No.	Parameter	Instrument	Least count	Range
3.2.1	Size (L, W, T)	Digital Vernier caliper	0.01 mm	-
3.2.2	Total soluble solids	Refractometer	-	0°-32° Briks
3.2.3	Angle of repose	An apparatus with stainless steel base (SS-316)	-	22.50 cm length and 15 cm width
3.2.4	Weight of custard apple fruits, seeds, pulp and core	Digital electronic weighing balance	0.05 g and 0.01 g	0- 6 kg and 0-350 g
3.2.5	Time	Stopwatch	0.5 sec	0-30 min

3.2.6	Force required for separating the custard apple seed from flake and Pulp stickiness	Brookfield Texture Analyzer (CT3)	-	50 kg load cell
3.2.7	Viscosity	Brookfield Viscometer DV-II+Pro	-	$\pm 1.0\%$

3.3 Experimental Details

Three separate experiments/parts conducted are listed below

Part I: Measurement of engineering properties of custard apple.

Part II: Modification and development of custard apple pulp-flakes extractor.

Part III: Test the performance of custard apple pulp-flakes extractor.

3.3.1 Measurement of engineering properties of custard apple fruit and seed

The custard apple fruits of Cv. Local with uniform size were procured from local market and from the orchards of progressive farmers of Nashik and Ahmednagar district. Engineering properties of custard apple were measured and calculated according to the procedure reported by Kad *et al.* (2015).

3.3.1.1 Measurement of physical properties

Twenty five fruits were selected randomly and their spatial dimensions were measured using digital vernier caliper having a least count of 0.01 mm. Custard apple seeds immediately after separation from pulp were used for determination of physical properties. Their length (along major axis), width (along intermediate axis) and breadth (along minor axis) was measured. The size, sphericity, volume, bulk density, true density, porosity and angle of repose of the custard apple seeds was calculated using following formulae (Mohsenin, 1986 and Kad *et al.*, 2015).

$$Size = (abc)^{1/3}$$

$$Sphericity = \frac{(abc)^{1/3}}{a}$$

where,

a = Length (major axis), mm

b = Width (intermediate axis), mm

c = Breadth (minor axis), mm

Weight of each sample was taken on a weighing balance with 0.01mm least count and average percentage of peel, seed, carpellary pulp, gritty pulp, average number of seeds per fruit, weight of seed, fruit to pulp ratio and pulp to seed ratio was calculated.

3.3.1.1.1 Bulk density

Bulk density defined as the ratio of total weight of sample to its total volume.

$$\text{Bulk density} = \frac{\text{Mass of seeds (g)}}{\text{Volume of seeds (mL)}}$$

3.3.1.1.2 True density

The ratio of sample mass to the true volume is termed as true density of the sample. It is determined by toluene displacement method.

$$\text{True density} = \frac{\text{Mass of seeds (g)}}{\text{Volume of toluene displaced by seeds (mL)}}$$

3.3.1.1.3 Porosity

Porosity was calculated by using the following formula.

$$\text{Porosity (\%)} = \frac{\text{True density} - \text{Bulk density}}{\text{True density}} \times 100$$

3.3.1.1.4 Angle of repose

The angle of repose was calculated by using following formula.

$$\theta = \tan^{-1}(h/L)$$

Where, θ - Angle of repose in degree

h - Height of inclined plate from base, mm

L – Length of plate, mm

3.3.1.2 Determination of physical properties of custard apple seed with flake

Physical properties namely, bulk density and angle of repose of the custard apple seeds with flake was determined by same methods as mentioned in physical properties of custard apple seed.

3.3.1.3 Determination of physical property of custard apple flakes/pulp

Physical property namely, angle of repose of the custard apple flakes/pulp was determined by same method as mentioned in physical properties of custard apple seed.

3.3.1.4 Determination of rheological properties

3.3.1.4.1 Force required to separate the seeds from flakes

It is the force required to produce a major break/rupture in a sample to separate the seeds from the flakes was measured with the help of texture analyzer.

3.3.1.4.2 Pulp stickiness

Stickiness/adhesiveness is the work/force necessary to overcome the attractive forces between the surface of the product and the surface of the probe with which the product comes in contact. The value of stickiness is required for the adjustment of angle of casing and discharge of pulp – flakes outlet, so that pulp discharges smoothly and easily. It is commonly the textural property measured by texture analyzer and is multiplication of hardness and cohesiveness (Peleg, 1996, Breene, 2007 and Kad *et al.*, 2016).

3.3.1.4.3 Viscosity of pulp

The viscosity of custard apple pulp is measure of its resistance to gradual deformation by shear stress or tensile stress. The viscosity is required for determination of angle of outer casing and pulp-flakes outlet of the pulp-flakes extractor. The viscosity of fresh custard apple pulp samples was measures with the help of Viscometer.

3.3.2 Modification and development of custard apple pulp-flakes extractor

The existing machine was modified taking into account the different properties determined and explained under section 3.3.1, convenience, experience, judgment, ease and simplicity of machining and availability of material. Considerable thrust was laid upon precision, accuracy and ease of operation of the machine. The method of trial and error was used to modify the machine. The present machine was developed by the Department of Agricultural Process Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri. Initially the survey of manual pulp extraction was done at Saswad region of Pune district and Parner region of Ahmednagar district shown in Plate 3.11 to 3.13. The machine was developed with materializing the idea of extracting the pulp-flakes of custard apple by shearing the core material against the stainless steel wires with tension.

Design considerations

1. Raw material : Peeled custard apple
2. Engineering properties of raw material
3. Manual feeding : Hopper
4. Separation of seeds from pulp flakes
5. Retention of pulp flakes with minimum damage
6. Material of construction used for machine should not be reacting with pulp i.e. food grade stainless steel material (SS 316)
7. Power source : Single phase electrical motor



Plate 3.1 Custard apple fruits



Plate 3.2 Seeded pulp-flakes



Plate 3.3 Seeds of Custard apple fruits



Plate 3.4 Weighing of Custard apple fruits

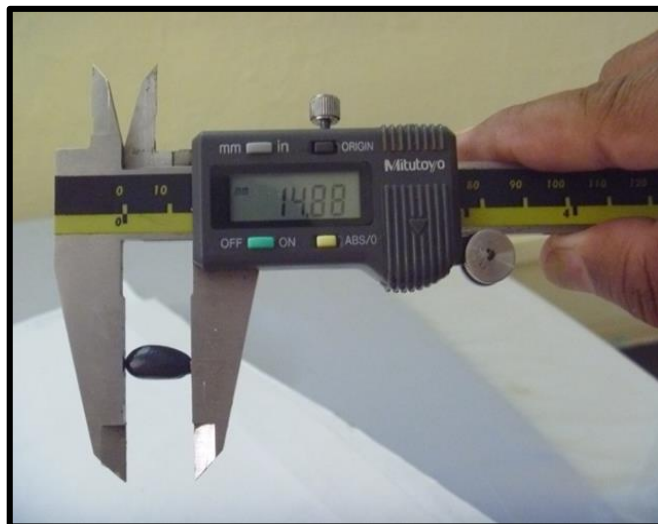


Plate 3.5 Physical properties of Custard apple seed



Plate 3.6 Texture Analyzer

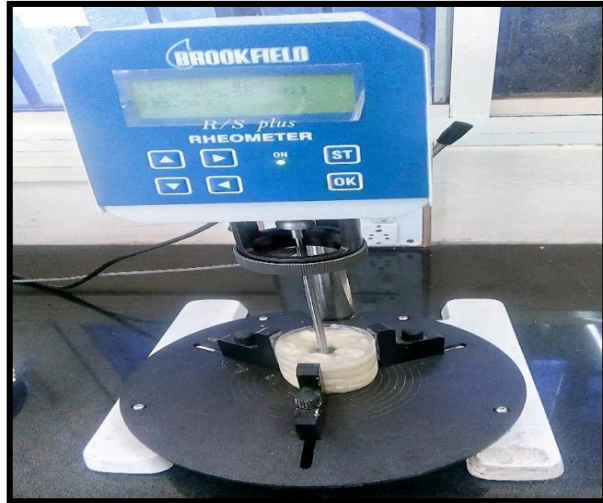


Plate 3.7 Brookfield Viscometer DV-II+Pro



Plate 3.8 Measurement of Seed separation force



Plate 3.10 Universal Testing machine

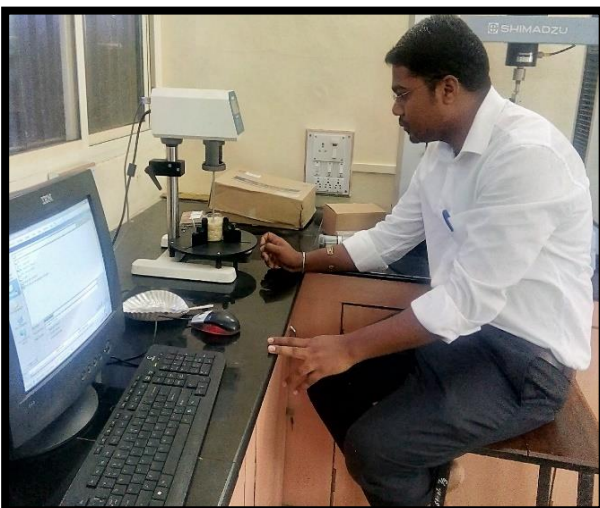


Plate 3.9 Measurement of Viscosity of pulp-flakes



Plate 3.11 Manual Pulp Extraction



Plate 3.12 Core removal process



Plate 3.13 Removing flakes by squeezing with nails

Design of machine was done with following sub-assemblies

1. Feeding hopper
2. Outer perforated casing
3. Extraction cylinder
4. Housing with seeds and pulp flakes outlet
5. Supporting frame with angular adjustments
6. Power source and transmission units

The machine consists of constructional parts such as feeding hopper, central wire mounted roller with shaft, outer perforated casing, seed outlet, pulp-flakes outlet, electrical motor drive with gear mechanism and frame on which all the parts were assembled. The solid and isometric view

of custard apple pulp-flakes extractor was shown in Fig. 3A and Fig. 3.1, respectively and Plate 3.14.

3.3.2.1 Main Frame

The main frame of custard apple pulp-flakes extractor being the important part of separator on which other parts were mounted. The size and material were selected on the basis of total weight of the major components mounted on it. The main frame was fabricated by using stainless steel using square pipe of size 40 mm × 40 mm to supports the components (Fig. 3.1 and 3.2). The overall dimension of frame was 470 mm x 455 mm x 481 mm. The height of the main frame was kept as 481 mm at hopper end and 410 mm at outlet end. Two support bolts with lock nuts of 12.5 mm Φ – 150 mm in length were used on hopper end and four nuts bolts of 6 mm Φ – 15 mm in length were used with on outlet end. The required angle of extraction mechanism was then achieved by changing the position of lock nuts on the support bolts.

3.3.2.2 Extraction cylinder (stainless steel wires cylinder)

An extraction cylinder is shown in Fig. 3.4 and Fig. 3.5 (Plate 3.15) and is the most important assembly of the machine. It was made with greater precision and accuracy, which consist of various components discussed as follows,

3.3.2.2.1 Main shaft

A stainless steel shaft (Fig.3.5), having 35 mm diameter and 675 mm length was used for power transmission and mounting the stainless steel wires cylinder. The design of shaft was made on the basis of twisting moment transferred from power source. The diameter of the shaft at feed end was 26 mm to mount the pinion operated by gear on the motor shaft. The stainless steel wires roller was developed with solid upper disc mounted at a distance of 185 mm from the feed end and spoked lower disc at a distance of 37 mm from the discharge end. Discharge end of the shaft with a diameter of 25 mm was supported by the taper roller bearing provided at the center of seed outlet.

3.3.2.2.2 Wire Tightening Mechanism

In order to provide even tension to each wire a “wire tightening mechanism” was developed shown in Fig. 3.4 and Fig. 3.5 (Plate 3.22). The holding disc which is having 160 mm diameter fixed on shaft having 4 number hole of 7 mm diameter and same as on upper disc. 4 numbers of holes of 6 mm diameter were made on the upper disc. The fix disc attached to upper disc with nut bolts. The middle disc and lower disc fixed on their passion. Stainless steel wire of 0.40 mm thickness were passing through hole which provide edges of all disc. The bolts were tightened with spanner and upper disc move toward holding disc for achieving proper tension of the wires, and fixed them.

3.3.2.2.3 Upper disc, Middle disc and Lower disc

Upper disc (Fig.3.4 and Plate 3.17) of 4 mm thickness and 193 mm in diameter was made up of stainless steel with proper machining. It was provided with central bore of 40 mm for move it on the shaft. It has also 145 numbers of hole having 1mm diameter. The pitch of hole was 3.50 mm. The spacing between two wires was finalized on the basis of dimensions of seeds.

Middle disc (Fig.3.4 and Plate 3.18) of 4 mm thickness and 196 mm in diameter was made up of stainless steel with three spocks keeping open space for delivery of seeds. It was provided with central bore of 36 mm for fixing it on the shaft. It has also 145 numbers of hole having 1 mm diameter.

Lower disc (Fig.3.4 and Plate 3.18) of 8 mm thickness and 198 mm in diameter was made up of stainless steel with three spocks keeping open space for delivery of seeds. It was provided with central bore of 36 mm for fixing it on the shaft. It has also 145 numbers of hole having 1 mm diameter and pitch of hole was 4 mm.

Stainless steel wires of 0.40 mm thickness were inserted through holes on upper, middle and to the lower disc.

3.3.2.2.4 Stainless steel wire

The shearing force required for separating flakes from the seeds was determined through the experiment carried out on Brookfield Texture Analyzer (CT3) (Plate 3.6 and 3.10). The thickness of wire as determined by considering shearing force of single carpel and total number of carpel along the length of cylinder. Thinner wire provide better shearing action which results in the better separation of pulp-flakes and seeds. The optimum size of stainless steel wire was found to be 0.40 mm in diameter. The wire spacing was decided from the study of physical properties of custard apple seeds. The minimum minor dimension of custard apple seed was found to be 4.27 mm. Hence the pitch is kept as 3.50mm at feed and 4 mm at discharge end, so that there was good shearing action between the central wire cylinder and outer perforated casing.

3.3.2.3 Outer perforated casing

The cylinder shape of outer perforated casing (Fig.3.9 and Plate 3.16) was made with a stainless steel-316 of 2 mm thickness. The exploded views of custard apple pulp-flakes extractor were shown in Fig.3.11. The inner diameter and length of the casing was 200 mm and 490 mm respectively. The stainless steel wires cylinder was surrounded with this outer perforated casing so as to have a sufficient clearance. The clearance between stainless steel wires cylinder and outer perforated casing was varied from 7 mm at feed end to 2 mm at the discharge end. The perforated casing was provided for applying pressure on carpel for the separation of pulp-flakes from the seeds.

3.3.2.4 Seed outlet

The seed outlet is shown in Fig.3.8 and Plate 3.20. The seeds separated from the pulp-flakes by passing through the wires, were conveyed to the seed outlet through the inside portion of cylinder and discharged through the seed outlet. The shape of seed outlet is semicircular having 181 mm in length and 116 mm in radius. The discharge end supporting assembly was provided with a bush of 37 mm ID at its center to support the discharge end of the shaft. The discharge end supporting assembly was attached to the casing by nuts and bolts.

3.3.2.5 Outer Casing

Extraction assembly covered with a cylindrical stainless steel cover of 3 mm thickness and diameter having 300 mm through length of 500 mm. The Outer Casing was provided for covering Extraction assembly and fixed to the main frame by nut bolts as shown in fig.3.3 and Plate 3.19.

3.3.2.6 Pulp-flakes outlet

The pulp-flakes outlet (Fig.3.7) platform of 360 mm x 400 mm was attached to bottom side of casing. The pulp-flakes outlet platform was inclined at an angle of 45 ° on the basis of angle of repose of pulp-flakes.

3.3.2.7 Feeding hopper

The hopper (Fig.3.6 and Plate 3.19) was trapezoidal in shape with a height of 150 mm. The cross section of the hopper was rectangular with a size of 235 mm x 225 mm at the top, and 175 mm x 130 mm at the bottom. The hopper was mounted tangentially on the outer casing so as to feed the raw material along the periphery of the stainless steel wires cylinder. The rotational motion of stainless steel wires cylinder draws the raw material in the working clearance between the stainless steel wires cylinder and outer casing. The slope of hopper with horizontal was 35°, which was kept more than angle of repose to ensure the proper flow. A similar mechanism was used in general fruit and vegetable pulping machine (Dostal, 1920), in which the feeding movement of the pulp from the grinding mechanism to centrifugal separating mechanism was facilitate to avoid the tendency of the material to choke at the entrance of the drum by reason of the momentum imparted to the material by the rotating action of the grinding mechanism.

3.3.2.8 Power transmission mechanism

The power transmission mechanism consists of A.C. induction electric motor (0.5 HP, 1440 rpm @ 50 Hz) coupled to the central shaft with the help of adjustable bracket and gear mechanism (Plate 3.21). The rotational speed of extraction cylinder was adjusted with the help of gear and pinion attached to the main shaft and motor for optimized after inspect the machine for core recovery, flakes recovery and seed separation efficiency.

3.3.3 Clearance between the central wires mounted roller and outer casing

The inner diameter of the outer casing was kept constant at 200 mm throughout its length of 490 mm. The variation of the clearance depends upon the diameter of the extraction cylinder. The extraction cylinder was made taper with upper disc of 193 mm diameter and lower disc of 198 mm in diameter. Hence the clearance between the roller and outer casing varies from 7 mm at feed end to 2 mm at discharge end. Higher clearance at feed end facilitates the raw material inside the clearance zone from the feeding hopper, while the decreasing clearance from 7 mm from feed end to 2 mm to discharge end, helps for separating the pulp-flakes from seed by pressing the raw material against the wires of extraction cylinder. It is found that the varying clearance from 1/16'' to 2'' between inner pressing drum and outer cylindrical screen was found to be effective for extracting the juice or pulp from various fruits and vegetables (Lindley, 1937). The clearance of greater than 4 mm was used, because the minimum thickness of the flakes with seeds was more than 4 mm. Similarly maximum clearance of 7 mm was used, since the minimum minor dimension of the seed was found to be 4.16 mm. Thus a varying clearance from 7 mm to 2 mm from the feed end to discharge end was kept for thorough separation of maximum seeds from pulp-flakes and conveying the pulp-flakes to the outlet after separation.

3.3.4 Operational details

Semi-automatic machine was operated by electrical motor. The feeding of raw material (peeled custard apple) was done manually into the hopper. The raw material was conveyed from hopper to the extracting cylinder. The material was passed through the clearance between housing and the extracting cylinder. By the action of shearing, pulp flakes were cut by the steel wires on the extracting cylinder. The seeds were passed through gap between the wires and collected at the seed outlet. The pulp flakes were conveyed along the periphery of housing and collected at pulp flakes outlet.

3.3.5 Testing of developed custard apple pulp-flakes extractor

The develop machine will test with effects of different parameters such as roller speed and angle of inclination for following aspects:

Independent variables

1. Revolution per minutes of roller
2. Angle of inclination of drum

Dependent variables

1. Core recovery
2. Flakes recovery
3. Seed separation efficiency

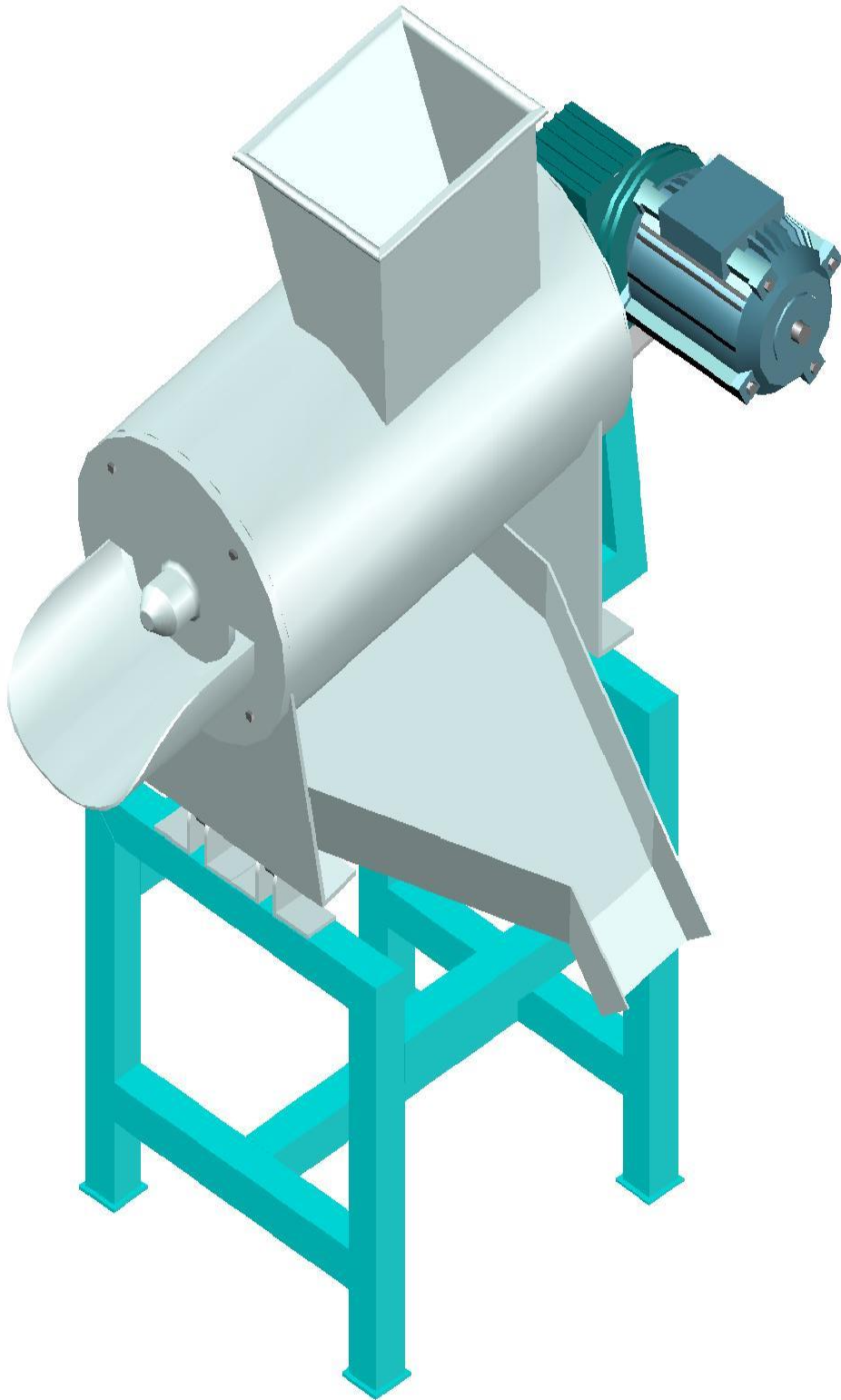


Fig. 3 SOLID VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR



Plate 3.14 Custard apple pulp-flakes extractor

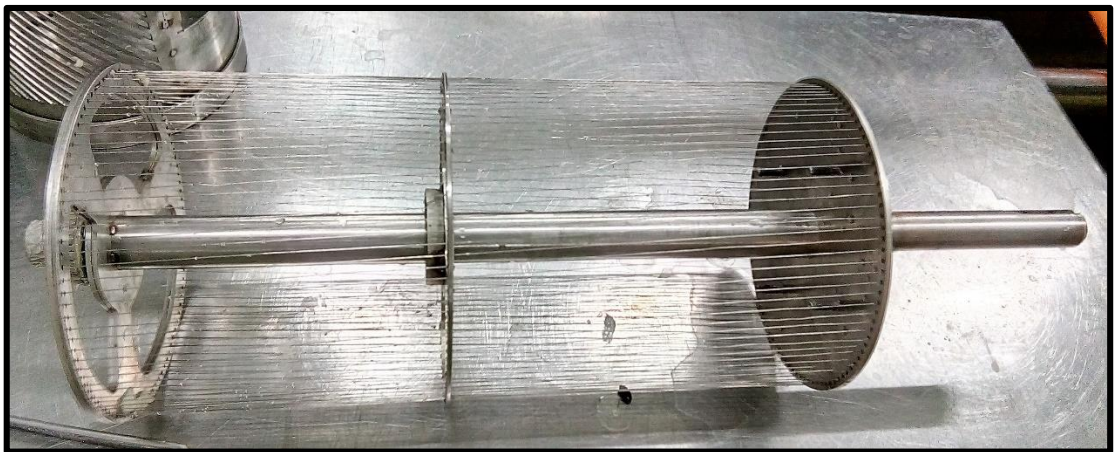


Plate 3.15 Extraction cylinder

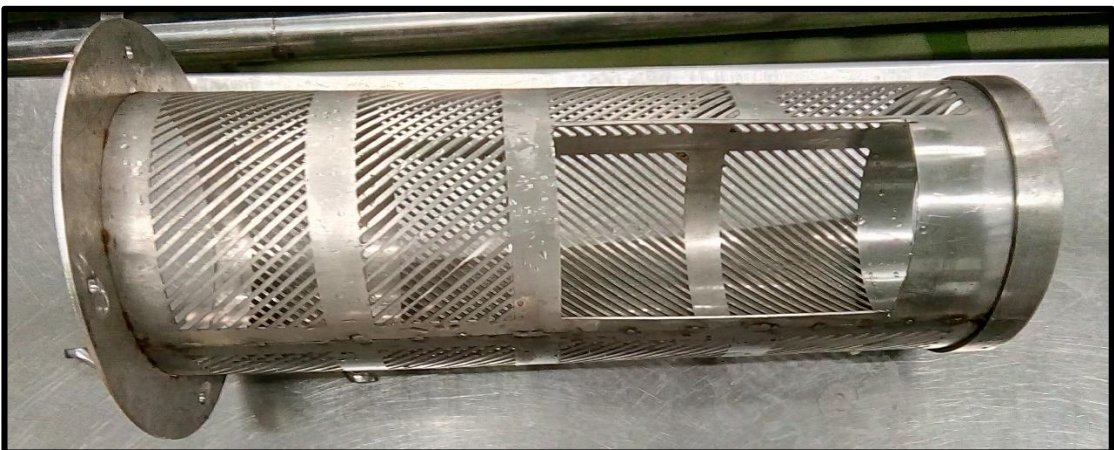


Plate 3.16 Outer perforated casing



Plate 3.17 Upper disc



Plate 3.18 Lower and Middle disc



Plate 3.19 Outer Casing with Feeding Hopper



Plate 3.20 Seed Outlet



Plate 3.21 D.C. Motor with Gear Box



Plate 3.22 Wire Tightening Mechanism

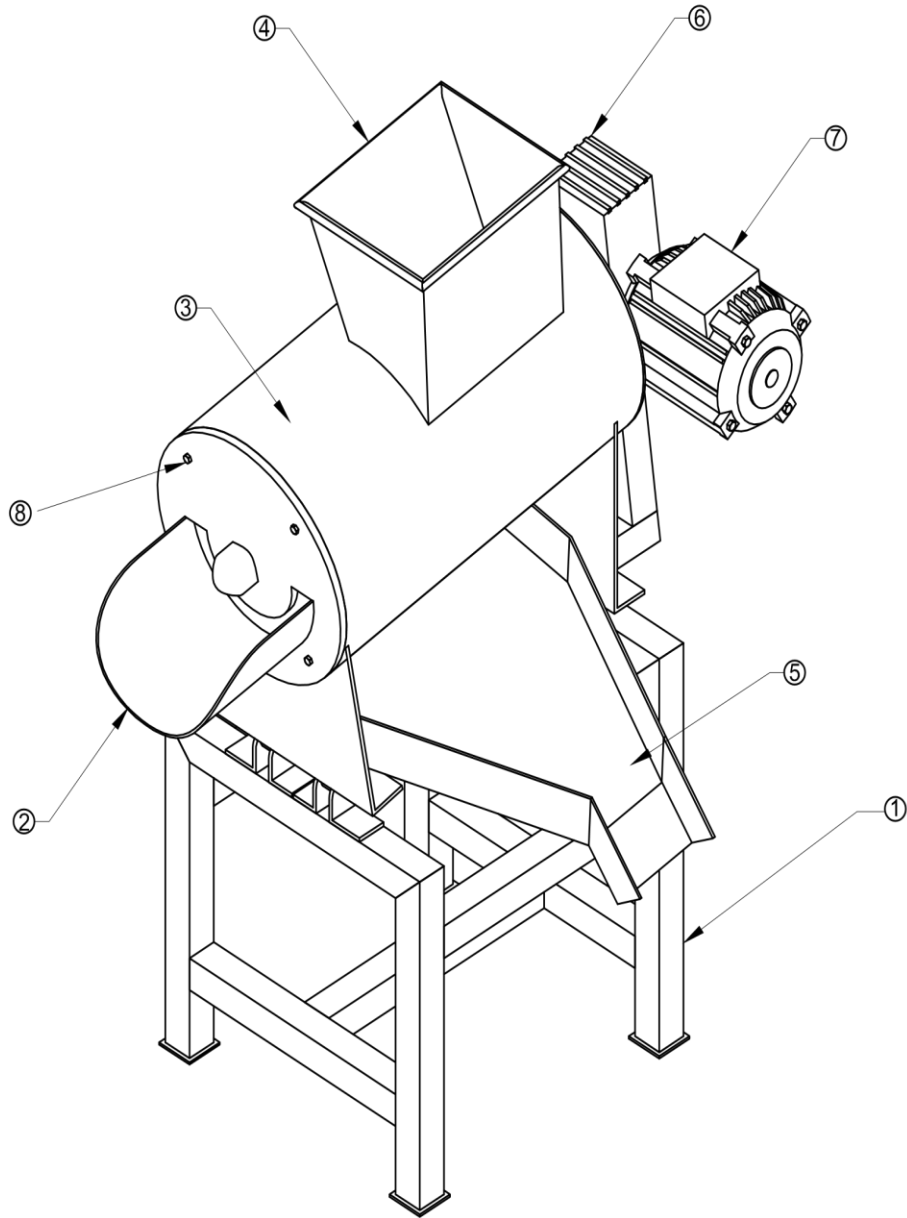


Fig. 3.1 ISOMETRIC VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR

PART NAME :- ISOMETRIC VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR				
		SHEET NO. 1 OF 1	SCALE :- NTS	
MATERIAL LISTED FOR		UNIT	UNIT REQ	
SR.NO	DESCRIPTION	PART NO	QTY	MATL
1	MAIN FRAME	1:1	01	SS
2	SEED OUTLET	1:2	01	SS
3	OUTER CASING	1:3	01	SS
4	FEEDING HOPPER	1:4	01	SS
5	PULP FLAKES OUTLET	1:5	01	SS
6	GEAR BOX	1:6	01	STD
7	ELECTRICAL MOTOR	1:7	01	STD
8	NUT BOLT	1:8	01	SS

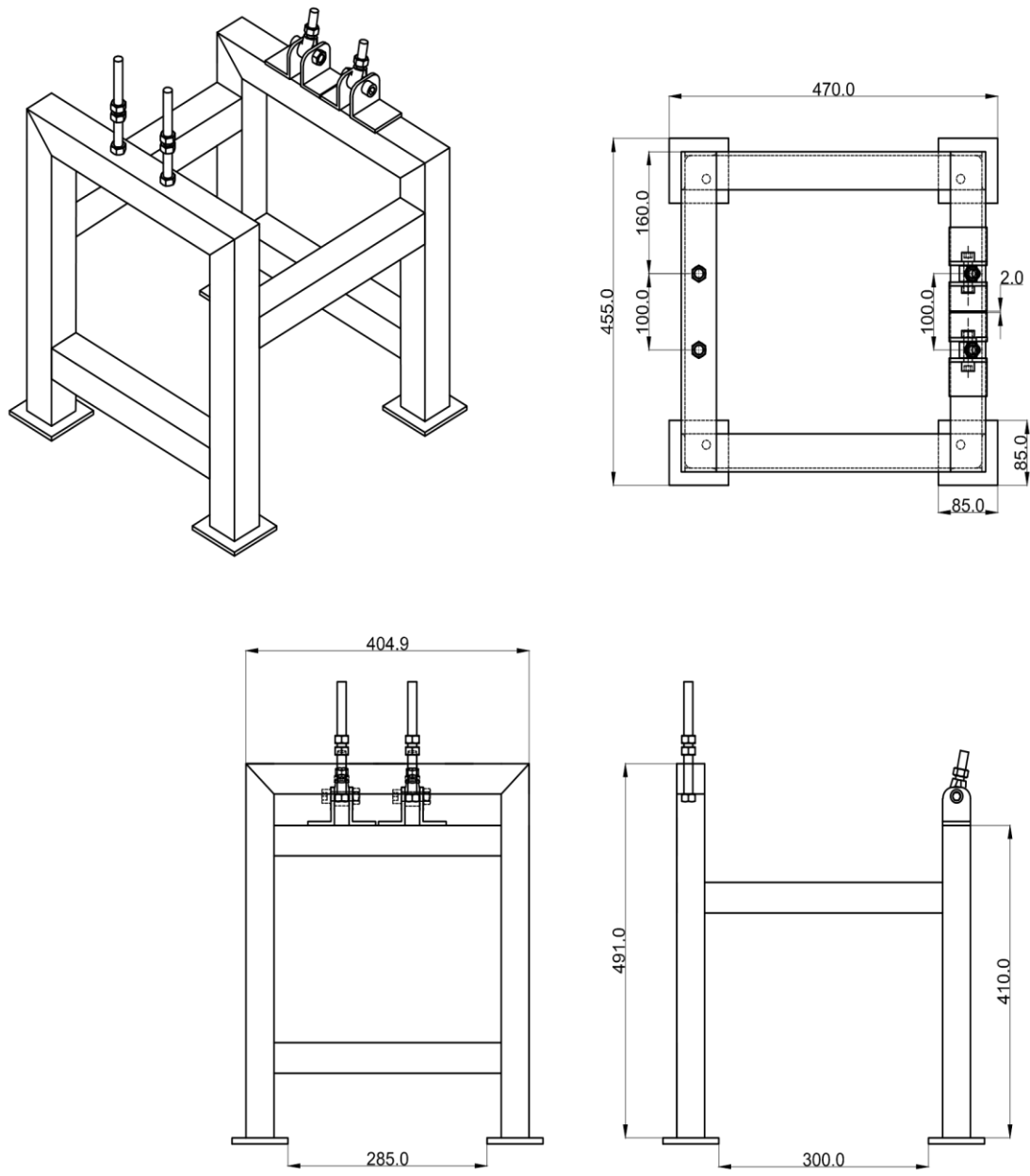


Fig. 3.2 ORTHOGRAPHIC VIEW OF MAIN FRAME FOR CUSTARD APPLE PULP - FLAKES EXTRACTOR

<p>NOTES</p> <p>1. ALL DIMENSIONS ARE IN MM.</p> <p>2. ALL JOINTS ARE FULL WELDED</p> <p>3. REMOVE ALL SHARP CORNER</p>	<p>PART NAME :- ORTHOGRAPHIC VIEW OF MAIN FRAME FOR CUSTARD APPLE PULP - FLAKES EXTRACTOR</p>	
	<p>SHEET NO.</p> <p>2 OF 1</p>	
	<p>SCALE :- NTS</p>	

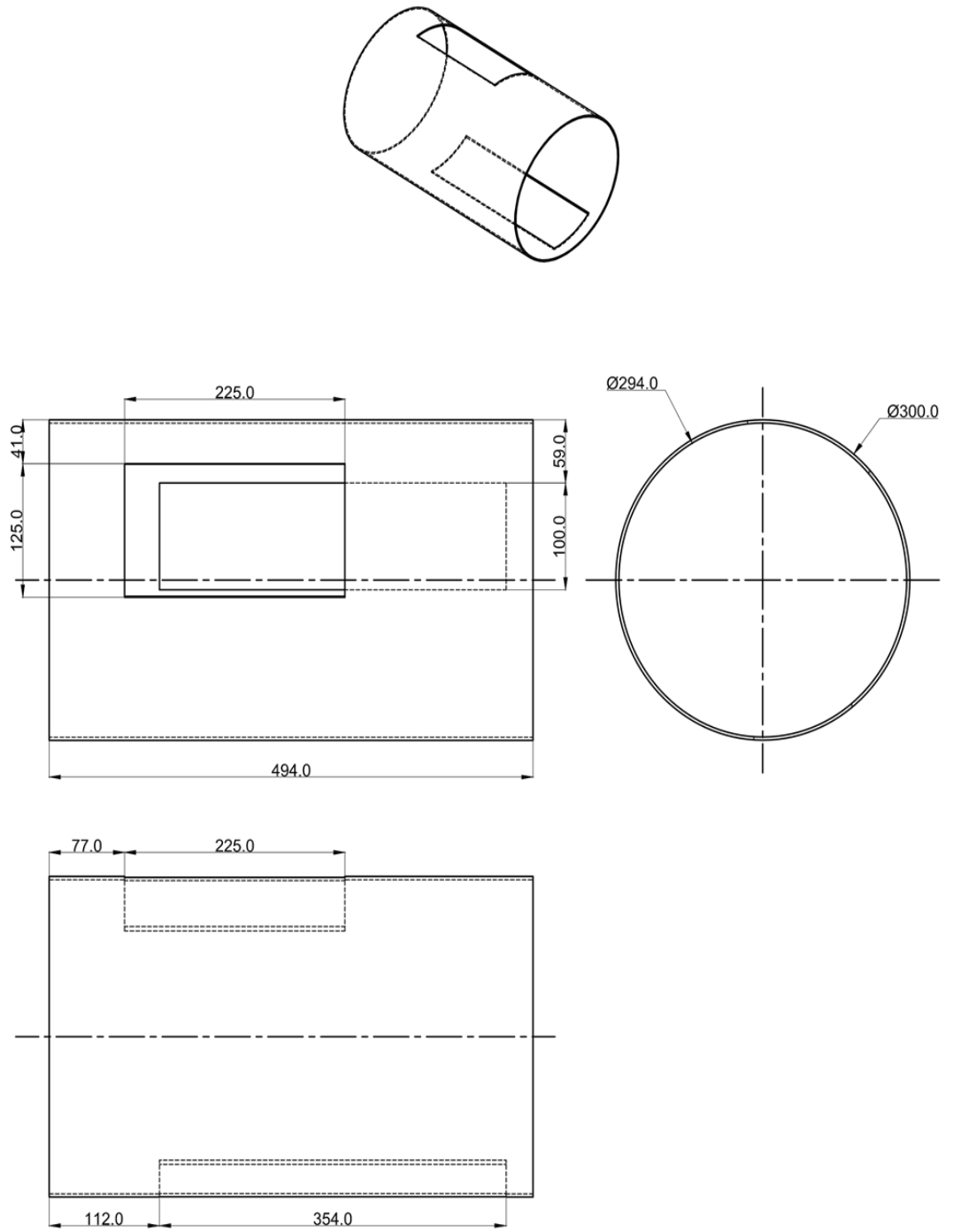
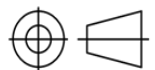


FIG. 3.3 DETAILED VIEW OF OUTER CASING

PART NAME :- DETAILED VIEW OF OUTER CASING

- 1. ALL DIMENSIONS ARE IN MM.
 - 2. ALL JOINTS ARE FULL WELDED
 - 3. REMOVE ALL SHARP CORNER
- NOTES

SHEET NO.
3 OF 1
SCALE : - NTS



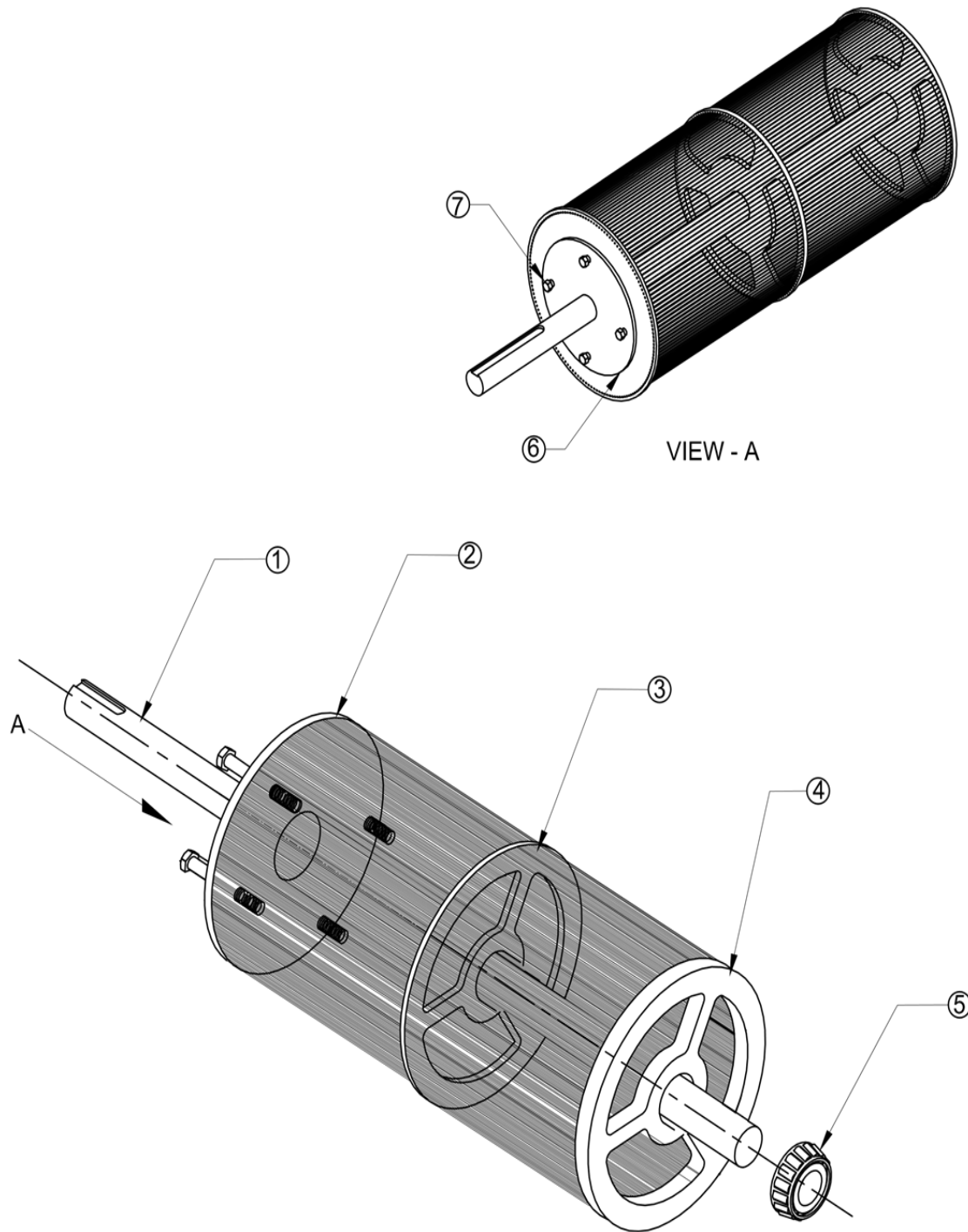


Fig. 3.4 ISOMETRIC VIEW OF EXTRACTION CYLINDER FOR CUSTARD APPLE PULP - FLAKES EXTRACTOR

PART NAME :- ISOMETRIC VIEW OF EXTRACTION CYLINDER FOR CUSTARD APPLE PULP - FLAKES EXTRACTOR				
SHEET NO.		SCALE :- NTS		
4 OF 1				
MATERIAL LISTED FOR		UNIT	UNIT REQ	
SR.NO	DESCRIPTION	QTY	MATL	
1	MAIN SHAFT	01	SS	
2	LOWER DISC	01	SS	
3	UPPER DISC	01	SS	
4	TAPPER ROLLER BEARING	01	SS	
5	TAPPER ROLLER BEARING	01	SS	
6	HOLDING PLATE	01	SS	
7	HEX NUT BOLT	04	SS	

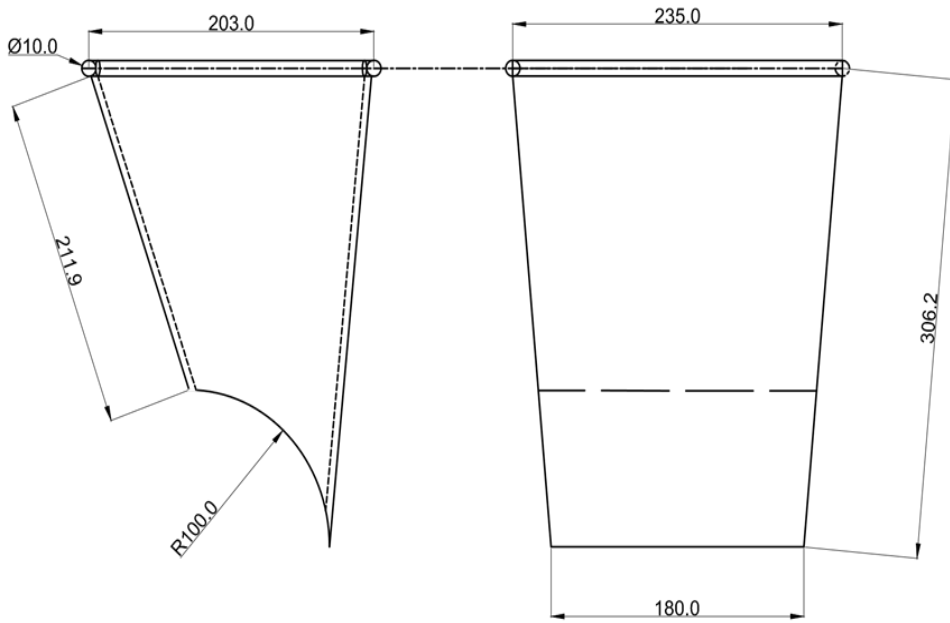
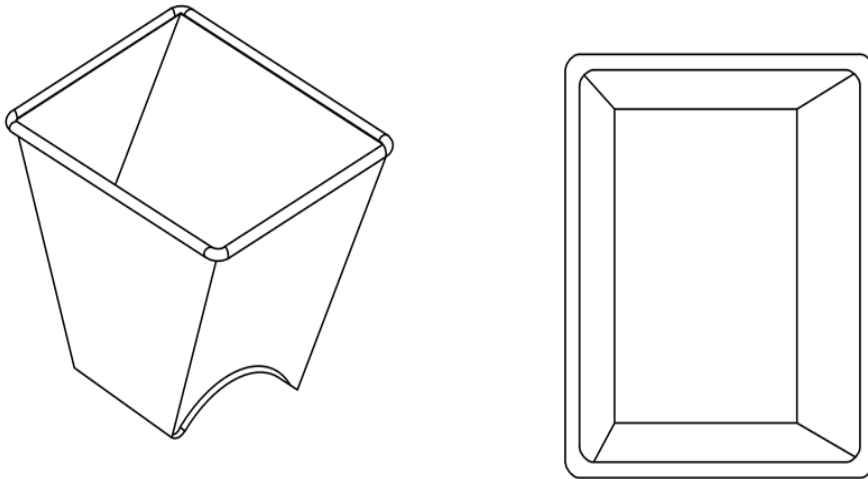


FIG. 3.6 DETAILED VIEW OF HOPPER

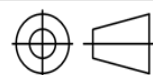
PART NAME :- DETAILED VIEW OF HOPPER

- NOTES
1. ALL DIMENSIONS ARE IN MM.
 2. ALL JOINTS ARE FULL WELDED
 3. REMOVE ALL SHARP CORNER

SHEET NO.

5 OF 1

SCALE :- NTS



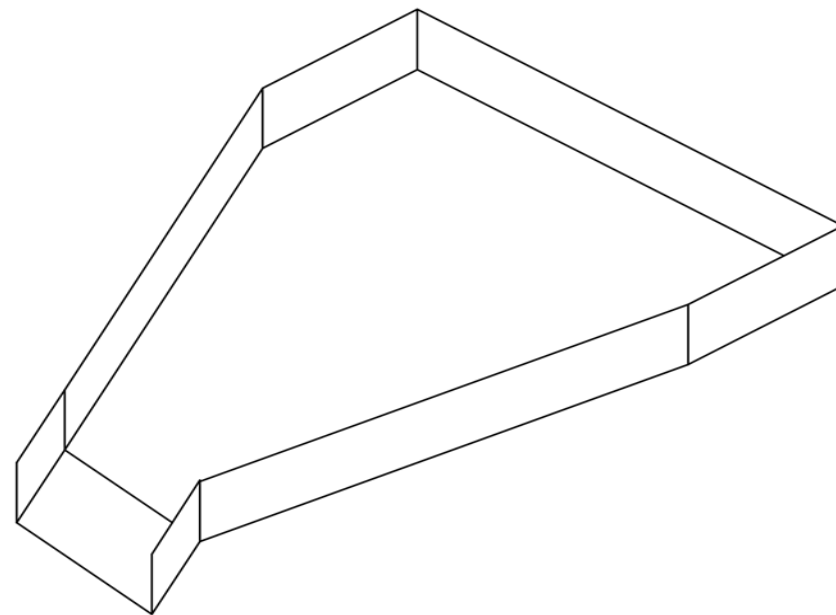
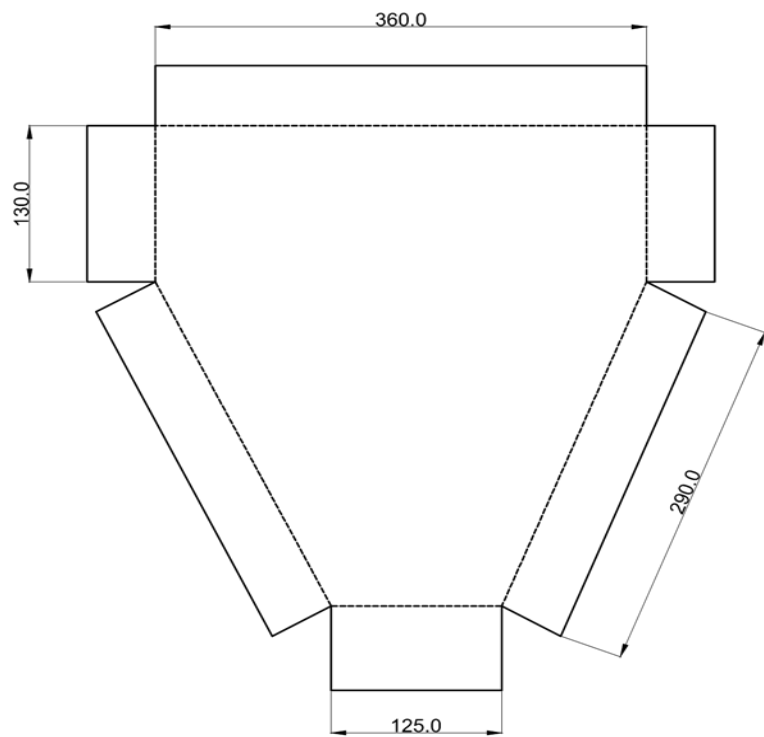


Fig. 3.7 ORTHOGRAPHIC VIEW OF PULP-FLAKES OUTLET

- NOTES
 1. ALL DIMENSIONS ARE IN MM.
 2. ALL JOINTS ARE FULL WELDED
 3. REMOVE ALL SHARP CORNER

PART NAME :- ORTHOGRAPHIC VIEW OF PULP-FLAKES OUTLET	
SHEET NO.	
6 OF 1	
SCALE :- NTS	

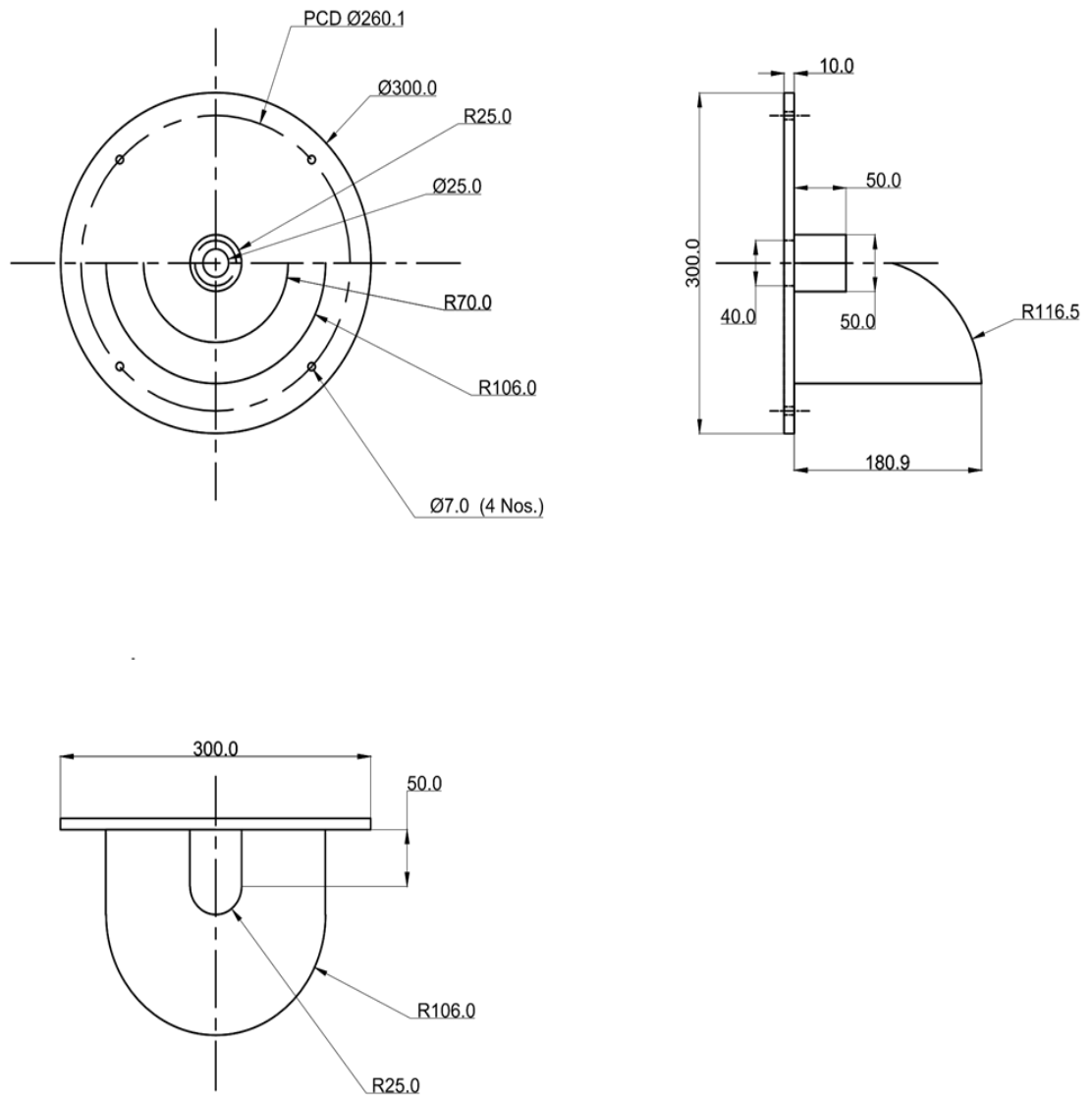


Fig.3.8 DETAILED VIEW OF SEED OUTLET FOR CUSTARD APPLE PULP - FLAKES

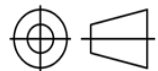
PART NAME :- DETAILED VIEW OF SEED OUTLET FOR CUSTARD APPLE PULP - FLAKES EXTRACTOR

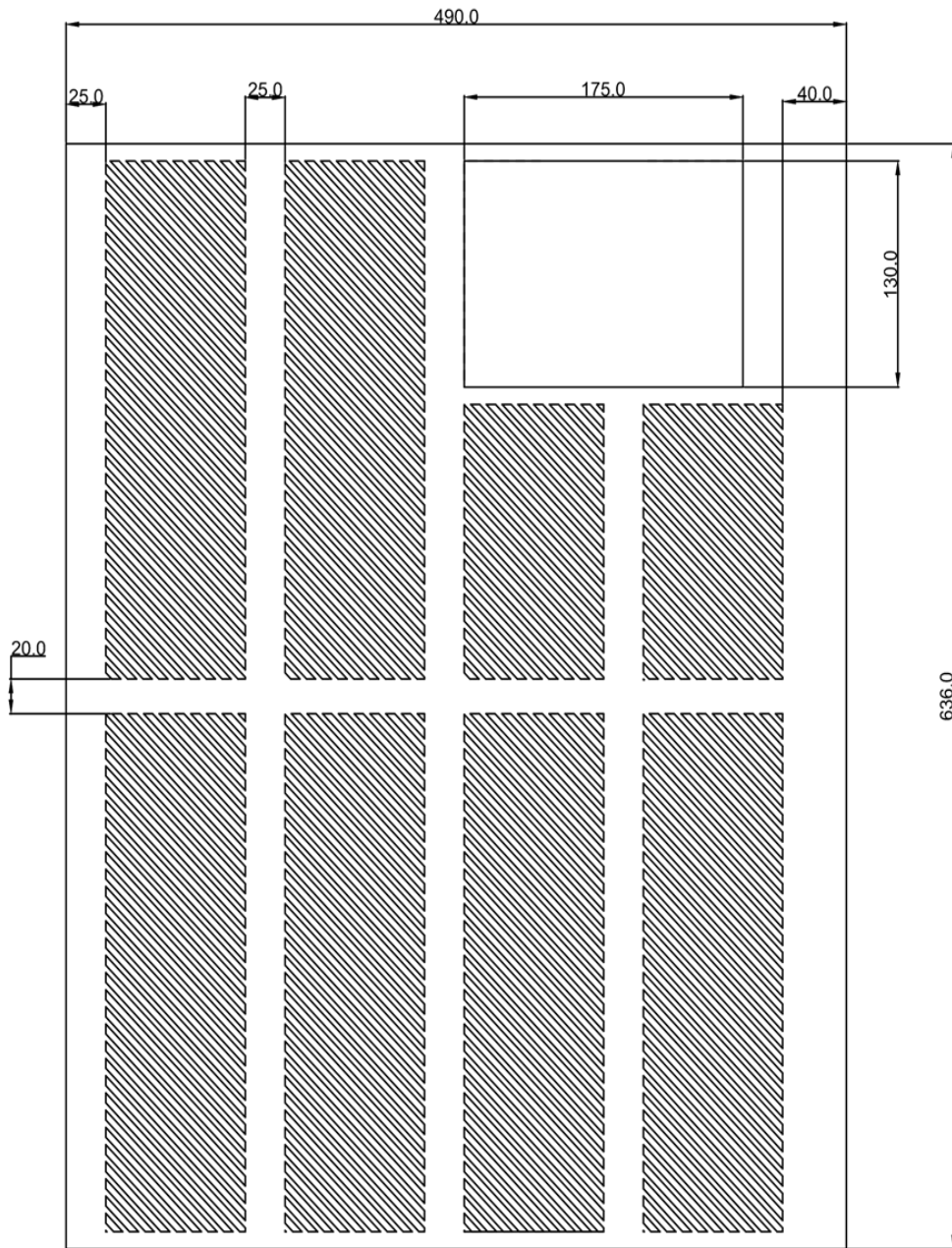
1. ALL DIMENSIONS ARE IN MM.
2. ALL JOINTS ARE FULL WELDED
3. REMOVE ALL SHARP CORNER

SHEET NO.

7 OF 1

SCALE :- NTS





3.9 DETAILED VIEW OF OUTER PERFORATED CASING SHEET DEVELOPMENT

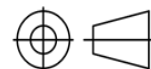
PART NAME :- DETAILED VIEW OF OUTER PERFORATED CASING SHEET DEVELOPMENT

- NOTES
1. ALL DIMENSIONS ARE IN MM.
 2. ALL JOINTS ARE FULL WELDED
 3. REMOVE ALL SHARP CORNER

SHEET NO.

8 OF 1

SCALE :- NTS



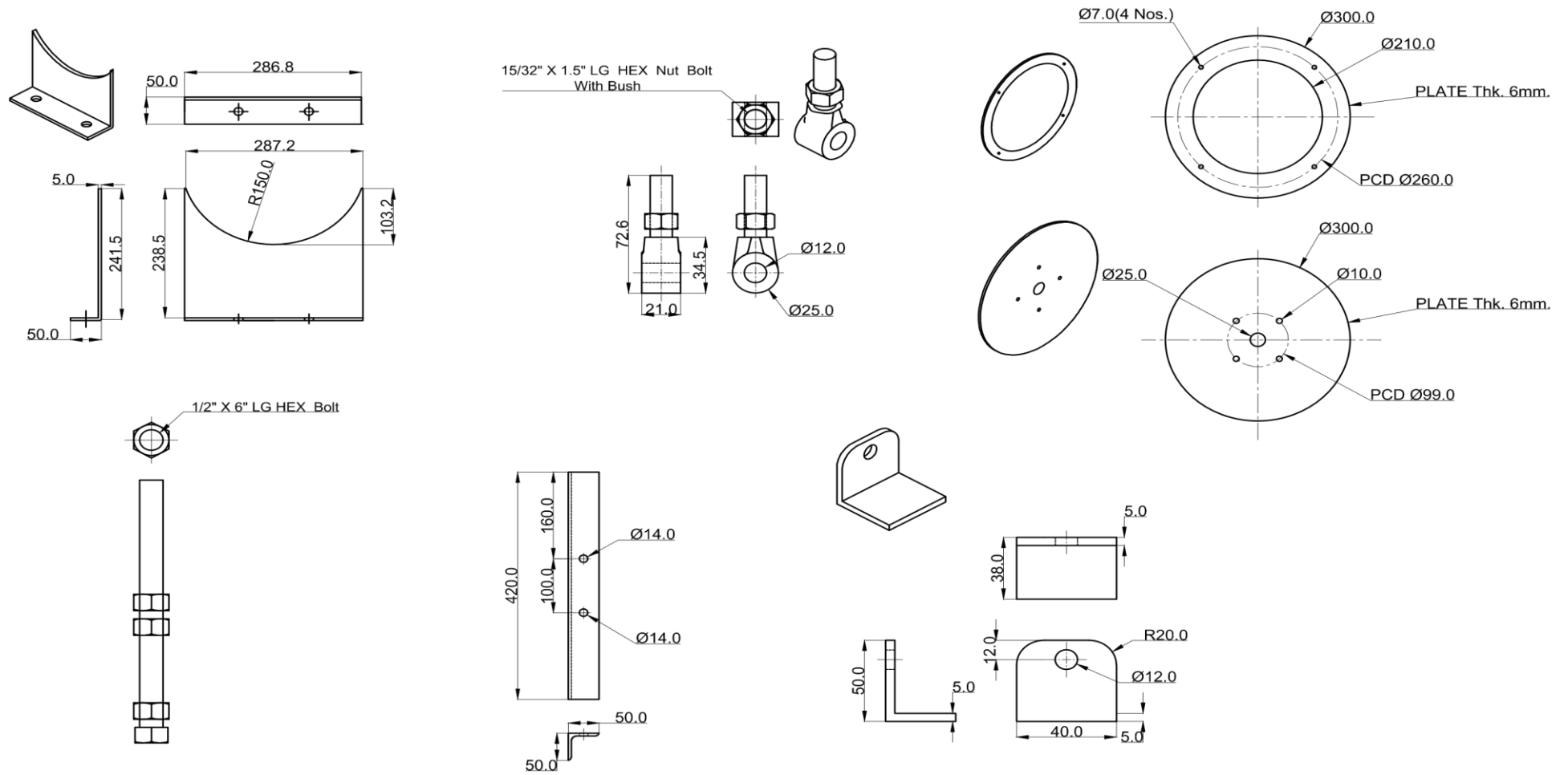


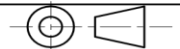
Fig.3.10 DETAILED PARTS OF CUSTARDAPPLE PULP - FLAKES EXTRACTOR

NOTES
 1. ALL DIMENSIONS ARE IN MM.
 2. ALL JOINTS ARE FULL WELDED
 3. REMOVE ALL SHARP CORNER

PART NAME :- EXPLODED VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR

SCALE :- NTS

SHEET NO.
 9 OF 1



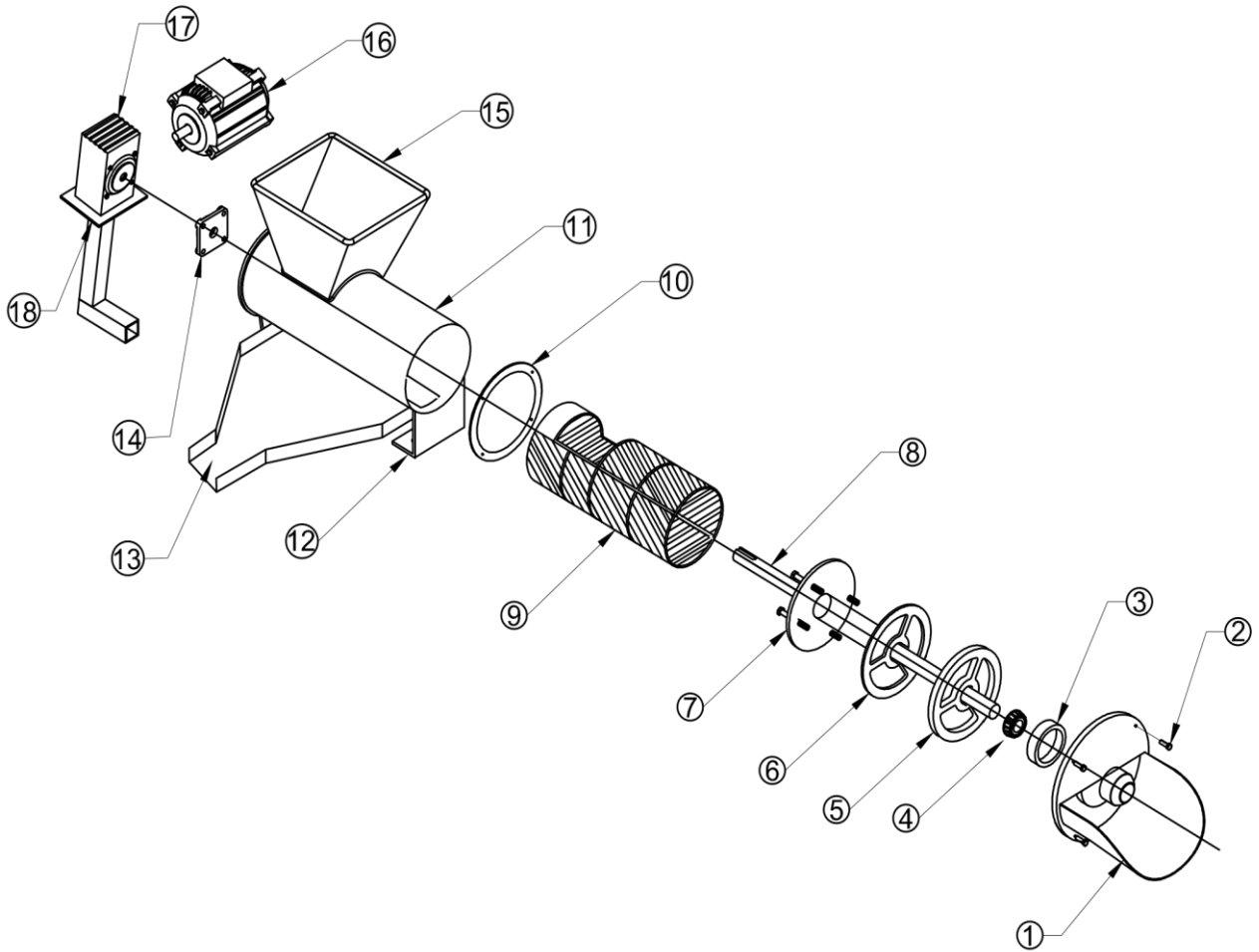


FIG. 3.11 EXPLODED VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR

PART NAME :- EXPLODED VIEW OF CUSTARD APPLE PULP - FLAKES EXTRACTOR				
SHEET NO.		SCALE :- NTS		
10 OF 1				
MATERIAL LISTED FOR	UNIT	UNIT REQ		
SR.NO	DESCRIPTION	QTY	MATL	
1	SEED OUTLET	01	SS	
2	NUT BOLT	08	SS	
3	TAPPET ROLLER BEARING HOUSING	01	SS	
4	TAPPER ROLLER BEARING	01	STD	
5	LOWER DISC	01	SS	
6	MIDDLE DISC	01	SS	
7	UPPER DISC WITH SCREW TAPPING MECHANISM	01	SS	
8	MAIN SHAFT	01	SS	
9	OUTER PERFORATED CASING	01	SS	
10	FLANGE	02	SS	
11	OUTER CASING	01	SS	
12	OUTER CASING HOLDING PLATE	02	SS	
13	PULP FLAKES OUTLET	01	SS	
14	F-205 FLANGE TYPE BEARING	01	STD	
15	FEEDING HOPPER	01	SS	
16	ELECTRIC MOTER	01	STD	
17	GEAR BOX	01	STD	
18	GEAR BOX MOUNTED SUPPORT PLATE	01	SS	

3.3.5.1 Core recovery

The core recovery for different speed of central roller was calculated by using following formula.

$$\text{Core recovery}(\%) = \frac{\text{Material at pulp outlet} + \text{Material at seed outlet}}{\text{Weight of core feed in hopper}} \times 100$$

3.3.5.2 Flakes recovery

The flakes recovery for different speeds of central roller and different angles of inclination was calculated by using following formula.

$$\text{Flakes recovery}(\%) = \frac{\text{Weight of flakes only}}{\text{Weight of pulp with flakes}} \times 100$$

3.3.5.3 Seed separation efficiency

The seed separation efficiency for different inclination angle was calculated by using following formula.

$$\text{Seed separation efficiency} (\%) = \frac{(\text{Total weight of seed material}) - (\text{Unseparated seeds found at seed outlet} + \text{Unseparated seeds found at pulp outlet})}{\text{Total weight of seed material}} \times 100$$

3.3.6 Experimental Design and Data Analysis

RSM has important applications in design development and formulation of new products, as well as in improvement of existing product design. The goal of RSM is to determine the optimum conditions for the system or to determine a region in the total space of the factors in which certain desirable conditions are satisfied. It defines the effect of independent variables, alone or in combination, on the processes. In addition to analyzing the effects of independent variables, this experimental methodology generates a mathematical model.

4. Results and Discussion

The research and development work on “Modification, development and performance evaluation of custard apple (*Annona squamosa* L.) pulp-flakes extractor” is discussed in this chapter. The results of research work for determining physical properties of custard apple fruits, seeds, custard apple seeds with flake and custard apple flakes/pulp are presented and discussed. The physico-morphological properties of custard apple fruits and performance of custard apple pulp-flakes extractor are presented and discussed. Experimental data on the seed size, sphericity, bulk density, true density, porosity and angle of repose for custard apple seeds are analyzed and presented in details. The measured properties of custard apple used for the development purpose are also discussed. The effect of roller speed and angle of inclination on performance of the machine in terms of core recovery, flakes recovery and seed separation efficiency are also presented in this chapter.

4.1 Physical properties

4.1.1 Physical properties of custard apple fruits

Table: 4.1.1 Physical properties of custard apple fruits (mean of twenty five samples)

Sr. No.	Length (mm)	Breadth (mm)	Thickness (mm)	Size (mm)	Sphericity (fraction)
1.	84.68	77.86	71.05	77.66	0.92

The linear dimensions of randomly selected twenty five custard apple fruits of Cv. Local (Appendix-A) and (Table 4.1.1.) The result were in agreement with Dhumal (1994), Pal and Kumar (1995), Pawar (2012) , Kad *et al.* (2015), Jadhav *et al.* (2015), Kumar *et al.* (2015) and Ramesh *et al.* (2016) for length, breadth, thickness, size and sphericity of custard apple fruits.

4.1.2 Physico-morphological properties of custard apple fruits

The measured physico-morphological properties of custard apple fruits (Cv. Local) are shown in Appendix-B, Table 4.1.2. The average weight of fruit and seed was 251.78 g and 0.33 g, respectively. The average peel, carpellary pulp, gritty pulp and seeds were found to be 42.56, 36.74, 12.87 and 7.92 per cent, respectively. The average number of seeds, total weight of pulp, fruit to pulp ratio and pulp to seed ratio were found to be 59.88, 125.50 g, 2.05 and 6.89, respectively.

All these results were in agreement with Rao and Subramanyam (2011), Pawar (2012), Kad *et al.* (2015), Jadhav *et al.* (2015) and Bakane *et al.* (2016), who studied the physico-morphological properties of custard apple fruits.

Table 4.1.2 Physico-morphological characteristics of custard apple fruit (mean of twenty five samples)

Sr. No	Weight of fruit (g)	Peel	Carpillary pulp	Gritty pulp	Number of seeds per fruit	Weight of Seeds per fruit	Weight Per seed	Total weight of pulp	Fruit to pulp ratio	Pulp to seed ratio
		(g)	(g)	(g)		(g)	(g)	(g)	(g)	(g)
1.	251.78	107.70 (42.56%)	93.07 (36.74%)	32.45 (12.87%)	59.88	19.99 (7.92%)	0.33	125.52	2.05	6.89

4.1.3 Physical properties of custard apple seeds

4.1.3.1 Linear dimensions and seed size

Linear dimensions of randomly selected fifty custard apple seeds were measured (Appendix-C). The average respective length, breadth and thickness was found to be 14.58 mm , 7.73 mm and 5.22 mm, respectively of a fresh seeds, whereas average seed size and sphericity was 8.35 mm and 0.58, respectively as shown in Table 4.1.3.

The results were in agreement with Thakur and Singh (1966), who reported that the custard apple seeds were oblong in shape with an average length of 11.2 mm and a breadth of 6.8 mm. The minimum minor dimension of the custard apple seed was found to be 4.2 mm. The linear dimensions and seed size were in agreement with Pawar (2012), Kad *et al.* (2015) and Ramesh *et al.* (2016) for custard apple seed.

Table: 4.1.3 Average linear dimensions, seed size and sphericity of custard apple seeds (Mean of twenty five samples)

Sr. No.	Major axis (mm)	Medium axis (mm)	Minor axis (mm)	Seed size (mm)	Sphericity (fraction)
1.	14.58	7.73	5.22	8.35	0.58

4.1.3.2 Sphericity

The values determined for sphericity of custard apple seeds are shown in Table 4.1.3. It was found that the sphericity was reported to be 0.58 mm. The results were also in agreement with results reported for custard apple seed by Pawar (2012) and Kad *et al.* (2015).

4.1.3.3 Bulk density

Average of fifteen samples (Appendix-D) were reported as bulk density value of seed sample. The average values for bulk density of custard apple seeds are presented in Table 4.1.4. The bulk density was 648.28 kg/m³. The results were in agreement with Pawar (2012) and Kad *et al.* (2015) for custard apple seeds.

Table: 4.1.4 Bulk density, true density, porosity and angle of repose of custard apple seeds

Sr. No.	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)	Angle of repose (°)
1.	648.28	898.19	27.81	15.28

4.1.3.4 True density

The data on true density depicted in Appendix-D and the average values for true density of custard apple seeds is given in Table 4.1.4. The measured values of true density were 898.19 kg/m³. The results are in agreement with Pawar (2012) and Kad *et al.* (2015) for custard apple seeds.

4.1.3.5 Porosity

The data on porosity of custard apple seeds were calculated (Appendix-D) and average values was shown in Table 4.1.4. It was found that, the porosity of custard apple seeds 27.81 per cent. The results are in agreement with Pawar (2012) and Kad *et al.* (2015) for custard apple seeds.

4.1.3.6 Angle of repose

The average of fifteen samples (Appendix-D) for angle of repose was shown in Table 4.1.4. The results indicated that the angle of repose value for custard apple seed was 15.28° . The similar results were reported by Pawar (2012) and Kad *et al.* (2015) for custard apple seeds.

4.1.4 Physical properties of seed with flake**4.1.4.1 Bulk density and angle of repose**

The data on bulk density and angle of repose depicted in Appendix-E and the average values of fifteen samples for bulk density and angle of repose of custard apple seed with flakes is given in Table 4.1.5. The measured value of bulk density and angle of repose were 876.25 kg/m³ and 36.05°, respectively. The results were in agreement with Pawar (2012), Pate *et al.* (2014) and Kad *et al.* (2015) for custard apple seed with flake.

Table: 4.1.5 Measurement of bulk density and angle of repose of custard apple seed with flake

Sr. No.	Bulk density (kg/m ³)	Angle of repose (°)
1.	876.25	36.05 °

4.1.5 Physical property of flakes/pulp

4.1.5.1 Angle of repose

The average of fifteen samples (Appendix-F) for measuring the angle of repose of pulp/flakes was studied and shown in Table 4.1.6. The results indicated that the angle of repose value for custard apple pulp/flakes was 45.77° . The similar results were reported by Pawar (2012), Pathak *et al.* (2014) and Kad *et al.* (2015) for custard apple pulp-flakes.

Table: 4.1.6 Measurement of angle of repose of custard apple pulp/ flakes

Sr. No.	Angle of repose ($^\circ$)
1.	45.77°

4.1.6 Rheological Properties

4.1.6.1 Shear force required to separate the seeds from flakes

The maximum shear force required to separate seeds from flakes was 3.20 N (Table 4.1.7). The thickness of wire is determined on the basis of shearing force of single carpel and total number of carpel along the length of cylinder was 0.40 mm in diameter.

Table 4.1.7 Measurement of shear force required to separate the seeds from Flakes

Sr. No.	Replication	Shear force (N)
1	R1	2.60
2	R2	3.20
3	R3	2.65
4	R4	2.53
5	R5	3.01
6	R6	2.95
7	R7	3.16
8	R8	2.88
9	R9	2.26
10	R10	2.86
Average		2.71

The similar result was reported by Kad *et al.* (2016) that the shear force required for separating flakes from the seeds is 2.71 ± 0.14 .

4.1.6.2 Pulp stickiness

The data on pulp stickiness of fifteen custard apple pulp samples was calculated and an average value is shown in Table 4.1.8 and Appendix-G. The minimum, maximum and average measured values of stickiness of custard apple pulp were 25.2 g, 817.4 g and 240.40 g, respectively. The value of stickiness is required for the adjustment of angle of casing and discharge of pulp – flakes outlet, so that pulp discharges smoothly and easily.

Table 4.1.8 Measurement of pulp stickiness of custard apple pulp

Sr. No.	Replication	Hardness (g)	Cohesiveness	Stickiness (g)
1	R1	170	0.24	40.8
2	R2	280	0.20	56
3	R3	120	0.21	25.2
4	R4	455	0.38	172.9
5	R5	670	0.40	268
6	R6	635	0.31	196.85
7	R7	470	0.23	108.1
8	R8	500	0.24	120
9	R9	735	0.19	139.65
10	R10	540	0.33	178.2
11	R11	1340	0.61	817.4
12	R12	871	0.49	426.79
13	R13	1225	0.36	441
14	R14	694	0.34	235.96
15	R15	1185	0.32	379.2
Average				240.40

The results are in agreement with the values reported by Kad *et al.* (2016) for custard apple, Sigita *et al.* (2013) for apple pulp, Ahmad *et al.* (2005) for fruit bar made from papaya and tomato and Costell *et al.* (1995) for sweet orange.

4.1.6.3 Viscosity of pulp

The average value of ten samples for viscosity and torque of custard apple pulp is given in Table 4.1.9. The measured values of viscosity and torque were 50.65 cP and 32.73 Nm, respectively. The viscosity is required for determination of angle of outer casing and pulp-flakes outlet of the pulp-flakes extractor.

The results are in agreement with the values reported by Kad *et al.* (2016) for custard apple, Sigita *et al.* (2013) for apple pulp and Shahnawaz and Shiekh (2011) for jamun fruit juice, squash and jam.

Table 4.1.9 Measurement of viscosity of custard apple pulp

Sr.No.	Sample	Replication	Viscosity (cP)	Torque Nm
1	Custard apple pulp	R1	50.7	32.1
2		R2	52.8	33.6
3		R3	51.9	34.1
4		R4	52.07	34.9
5		R5	45.22	32.0
6		R6	48.38	30.9
7		R7	50.1	31.4
8		R8	52.4	32.6
9		R9	51.9	33.5
10		R10	51.0	32.2
Average			50.65	32.73

4.2 Performance evaluation of Custard Apple Pulp-Flakes Extractor Machine

Performance evaluation of the developed machine was carried out to see the effect of roller speed (30, 50, 70 and 90 rpm) and inclination angle of drum (20, 30 and 40°) on core recovery, working capacity, seed separation efficiency and flakes recovery and the results have been presented in Table 4.2.1 to 4.2.3.

4.2.1 Response surface for working capacity

Response surface for working capacity has been shown in Fig. 4.2.1 and observed that the response of RPM of roller and inclination angle of drum was significant.

The equation for working capacity is

$$\begin{aligned}
 \text{Working capacity} & & R^2 &= 0.1000 \\
 &= 58.19(448.11) - 7.29RPM(6.97) \\
 &- 11.24 \text{ Angle}(26.67) - 0.0493RPM^2 (0.051) \\
 &+ 0.296\text{Angle}^2 - 0.059 \text{ Angle} * RPM (0.111)
 \end{aligned}$$

(Values presented in parenthesis are standard error of respected coefficient.)

$R^2 = 0.1000$ indicating that 10.00 per cent variation in working capacity is attributed to above two factors. Response surface plan is given in Fig. 4.2.1.

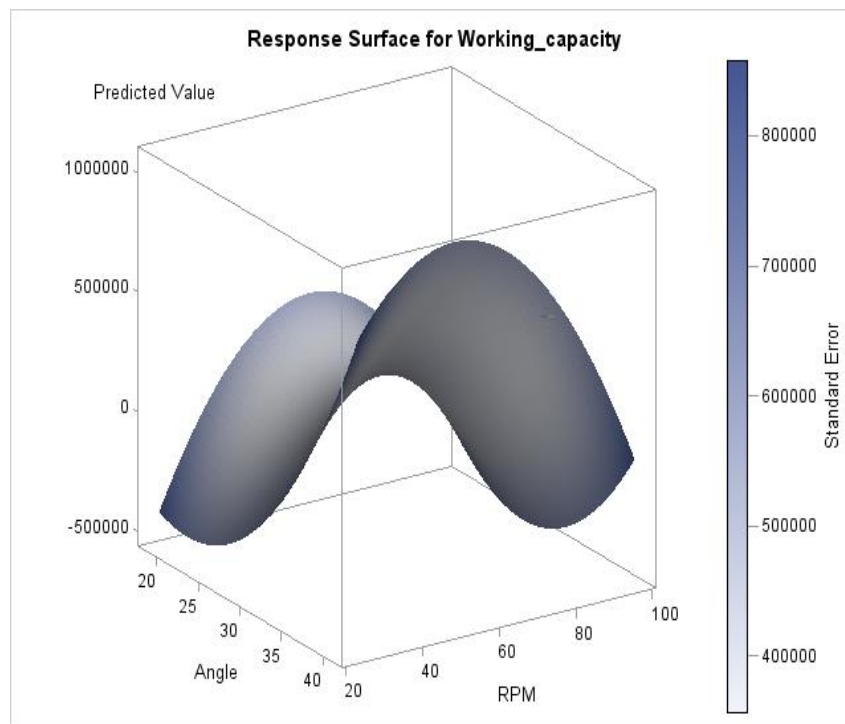


Fig. 4.2.1 Response surface plan for working capacity

As in response surface equation, the effect of RPM of roller on working capacity was found to be significant, while effect of inclination angle of drum was also found to be significant.

Table 4.2.1 Effect of roller speed at 20° angle of inclination on core recovery, seed separation efficiency and flakes recovery

Sr. No	RPM	Time required (min)	Weight of core (g)	Weight of material at pulp-flakes outlet (g)	Weight and number of seeds at pulp-flakes outlet (g)	Weight of seeds at pulp-flakes Outlet (%)	Weight of pulp-flakes at pulp-flakes outlet (g)	Weight of flakes only (g)	Weight of gritty pulp only (g)	Weight of material at seed outlet (g)	Weight of unseparated seeds at seed outlet (g)	Weight of unseparated seeds at seed outlet (%)	Working capacity (kg/h)	Seed Separation efficiency (%)	Core Recovery (%)	Flakes recovery (%)
1	30	8.16	4300	1830	13.03 (07)	0.71	1827.97	1434.40	393.57	1310	170	12.97	31.61	86.86	73.02	78.47
2	50	7.19	4500	1800.45	13.80 (08)	0.77	1798.65	1339.99	458.66	1350	130	09.63	37.55	90.23	70.01	74.50
3	70	5.38	4500	1890.40	12.92 (06)	0.68	1888.48	1305.13	583.35	1390	115	08.27	50.18	91.59	72.90	69.11
4	90	3.20	4500	1940.00	13.40 (07)	0.74	1938.60	1256.21	682.39	1330	130	09.77	84.37	90.12	72.67	64.80

Table 4.2.2 Effect of roller speed at 30° angle of inclination on core recovery, seed separation efficiency and flakes recovery

Sr. No	RPM	Time required (min)	Weight of core (g)	Weight of material at pulp-flakes outlet (g)	Weight and number of seeds at pulp-flakes outlet (g)	Weight of seeds at pulp-flakes Outlet (%)	Weight of pulp-flakes at pulp-flakes outlet (g)	Weight of flakes only (g)	Weight of gritty pulp only (g)	Weight of material at seed outlet (g)	Weight of unseparated seeds at seed outlet (g)	Weight of unseparated seeds at seed outlet (%)	Working capacity (kg/h)	Seed Separation efficiency (%)	Core Recovery (%)	Flakes recovery (%)
1	30	6.16	5100	3409	17.76 (12)	0.52	3391.24	2740.49	650.75	854.50	103.82	12.15	49.68	85.77	83.60	81.05
2	50	5.56	5100	3400	10.40 (08)	0.30	3389.59	2598.19	791.40	860.30	120.50	14	55.03	84.79	83.54	78.01
3	70	5.16	5100	3470	18.64 (12)	0.54	3451.35	2478.69	972.66	930.00	136.90	14.67	59.30	83.33	86.33	72.30
4	90	3.10	5100	3500	10.90 (07)	0.31	3489.10	2415.50	1073.10	994.50	145.50	14.63	98.70	84.27	88.13	69.50

Table 4.2.3 Effect of roller speed at 40° angle of inclination on core recovery, seed separation efficiency and flakes recovery

Sr. No	RPM	Time required (min)	Weight of core (g)	Weight of material at pulp-flakes outlet (g)	Weight and number of seeds at pulp-flakes outlet (g)	Weight of seeds at pulp-flakes Outlet (%)	Weight of pulp-flakes at pulp-flakes outlet (g)	Weight of flakes only (g)	Weight of gritty pulp only (g)	Weight of material at seed outlet (g)	Weight of unseparated seeds at seed outlet (g)	Weight of unseparated seeds at seed outlet (%)	Working capacity (kg/h)	Seed Separation efficiency (%)	Core Recovery (%)	Flakes recovery (%)
1	30	5.38	5100	2677.50	13.92 (09)	0.52	2675.58	2081.60	593.98	1450.50	180	12.40	56.88	87.46	80.94	77.80
2	50	4.15	5100	2703	12.56 (08)	0.46	2700.44	2011.82	688.62	1500.50	188	12.52	73.74	87.30	82.42	74.50
3	70	4.02	5100	2750.50	13.92 (10)	0.51	2748.58	1890.47	858.11	1530.50	197.50	12.90	76.12	86.97	83.39	68.78
4	90	3	5100	2840	13.60 (09)	0.44	2838.40	1840.13	998.27	1660.10	210	13.04	102	86.85	87.57	64.83

4.2.2 Response surface for seed separation efficiency

It is found that the response of RPM of roller and inclination angle of drum in response surface for seed separation efficiency was significant.

The equation for seed separation efficiency is

$$\begin{aligned} \text{Seed separation efficiency} & \quad R^2 = 0.8692 \\ & = 118.28(3.89) + 0.21RPM(0.060) - 2.61 \text{ Angle}(0.231) \\ & \quad - 0.00088RPM^2 (0.000439) + 0.0443\text{Angle}^2 (0.003721) \\ & \quad - 0.003075 \text{ Angle} * RPM (0.00096) \end{aligned}$$

$R^2 = 0.8692$ indicating that 86.92 per cent variation in seed separation efficiency is attributed to above two factors. Response surface plan is given in Fig. 4.2.2.

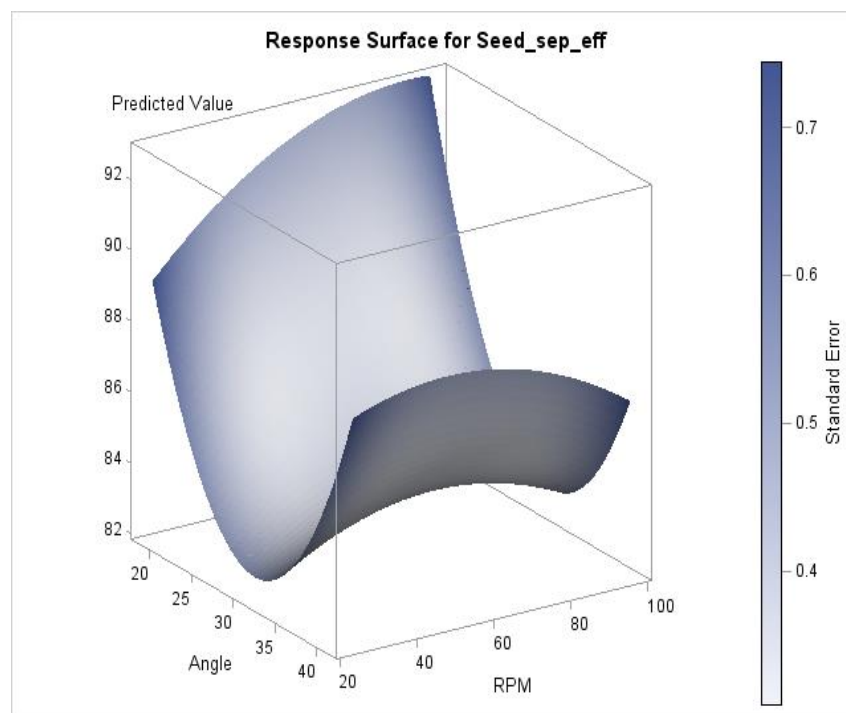


Fig. 4.2.2 Response surface plan for seed separation efficiency

As in response surface equation, the effect of inclination angle of drum was found to be non-significant, while RPM of roller and multiplication of RPM of roller and inclination angle of drum was found to be significant.

4.2.3 Response surface for core recovery

It is observed that the response of RPM of roller and inclination angle of drum was significant in response surface for core recovery.

The equation for core recovery is

$$\begin{aligned} \text{Core recovery} = & 12.38(7.56) - 0.24RPM(0.12) + 4.50 \text{ Angle}(0.45) \quad R^2 = 0.9210 \\ & + 0.0013RPM^2 (0.00085) - 0.069 \text{ Angle}^2 (0.0072) \\ & + 0.0051 \text{ Angle} * RPM (0.0019) \end{aligned}$$

$R^2 = 0.9210$ indicating that 92.10 per cent variation in core recovery is attributed to above two factors. Response surface plan is given in Fig.4.2.3.

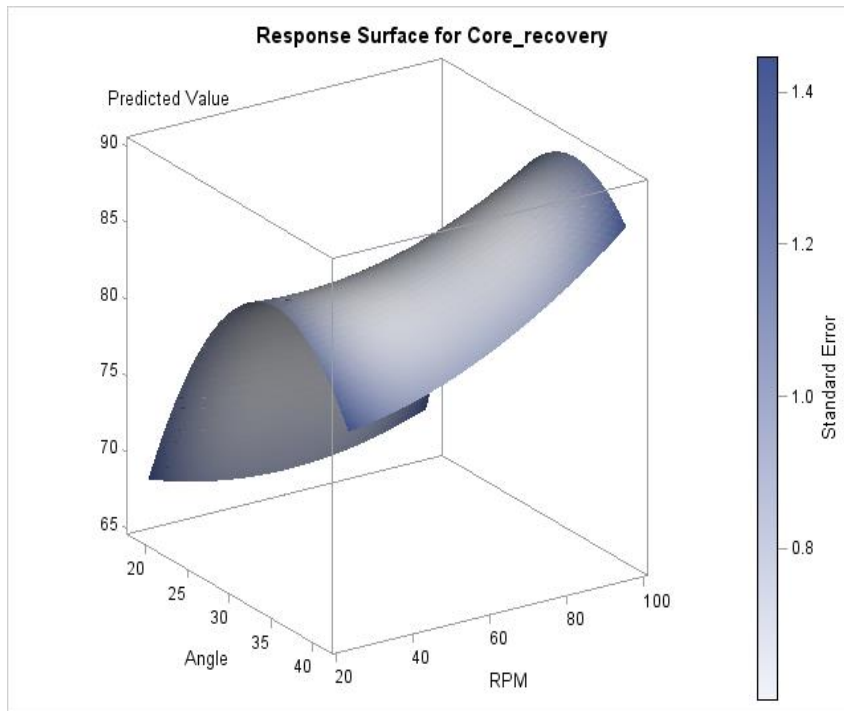


Fig. 4.2.3 Response surface plan for core recovery

As in response surface equation, the effect of RPM of roller found to be significant and inclination angle of drum was found to be non-significant, while multiplication of RPM of roller and inclination angle of drum was found to be significant.

4.2.4 Response surface for flakes recovery

As per the analysis of response surface for flakes recovery, it is observed that the response of RPM of roller and inclination angle of drum was significant.

The equation for flakes recovery is

$$\begin{aligned} \text{Flakes recovery} & \quad R^2 = 0.8927 \\ = & 46.52(6.85) - 0.052 RPM(0.101) + 2.57 \text{ Angle}(0.41) \\ & - 0.0010RPM^2 (0.00077) - 0.043 \text{ Angle}^2 (0.0065) \\ & - 0.0009 \text{ Angle} * RPM (0.0016) \end{aligned}$$

$R^2 = 0.8972$ indicating that 89.72 per cent variation in flakes recovery is attributed to above two factors. Response surface plan is given in Fig.4.2.4.

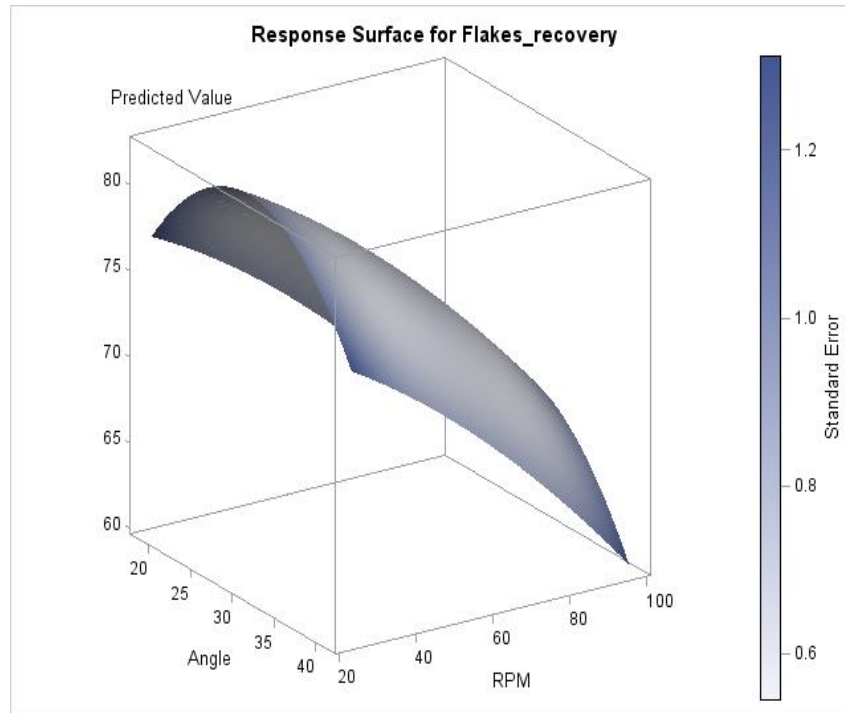


Fig. 4.2.4 Response surface plan for flakes recovery

As in response surface equation, the effect of RPM of roller found to be significant and inclination angle of drum was found to be non-significant, while the effect of multiplication of inclination angle of drum and RPM of roller was found to be significant.

4.2.5 Response contour for core recovery

The core recovery was mainly found to be depending upon the RPM of roller and inclination angle of drum. The trials were taken with a roller speed of 30, 50, 70 and 90 rpm and inclination angle of drum varying from 20 to 40°. The contour map of core recovery was shown in Fig 4.2.5. The core recovery was found to be increasing with increase in RPM of roller and inclination angle of drum. Maximum core recovery of 87.57 per cent was found for roller speed of 90 rpm and inclination angle of 40°.

The increased core recovery with increase in RPM of roller and inclination angle of drum was due to increased centrifugal force, which forced pulp-flake material away from the roller wires at pulp-flakes outlet and also due to increased vibrations of the machine with increase in roller speed.

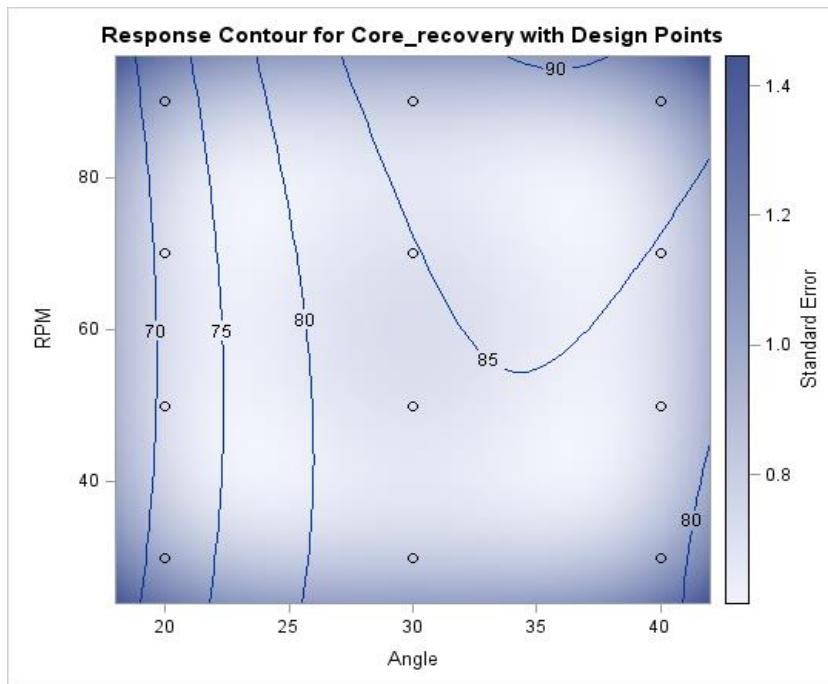


Fig. 4.2.5 Contour map for core recovery

4.2.6 Response contour for working capacity

The modified machine was tested for working capacity of machine. The working capacity was mainly found to be depending upon the RPM of roller and inclination angle of drum. The trials were taken with a roller speed of 30, 50, 70 and 90 rpm and inclination angle of drum varying from 20 to 40°. The contour map of working capacity was shown in Fig. 4.2.6.

The minimum working capacity of 31.61 kg/h was recorded at roller speed of 30 rpm and 20° inclination angle of drum, while maximum of 102 kg/h was for a roller speed of 90 rpm and 40° inclination angle of drum. It was observed that with increase in RPM of roller and inclination angle of drum, the working capacity was increased.

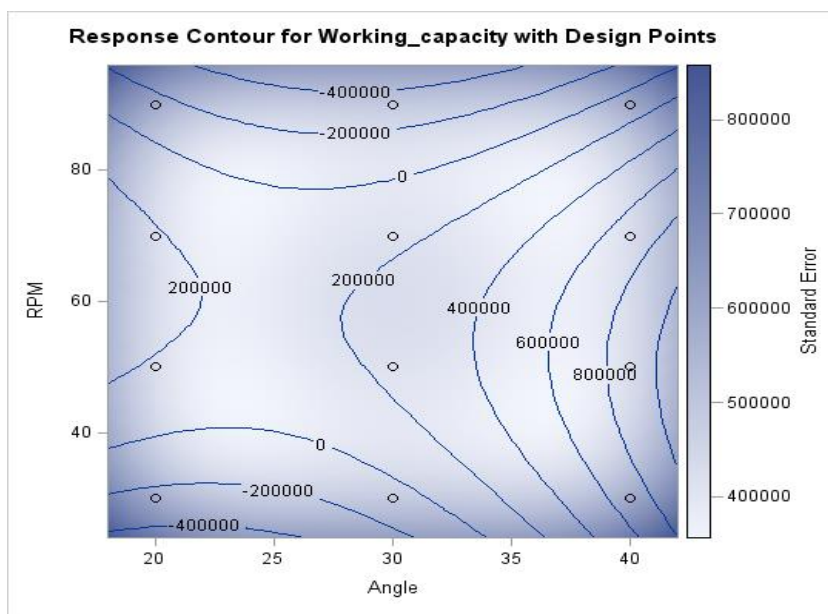


Fig. 4.2.6 Contour map for working capacity

The increased working capacity with increase in RPM of roller and inclination angle of drum was due to increased centrifugal force, which forced pulp-flake material away from the roller wires at pulp-flakes outlet and also due to increased vibrations of the machine with increase in roller speed

4.2.7 Response contour for seed separation efficiency

The developed machine was tested for efficiency of seed separation of the core material feed in the hopper by changing RPM of roller and inclination angle of drum. It was found that the seed separation efficiency was decreasing with increase in inclination angle of drum and RPM of roller (Fig. 4.2.7). A seed separation efficiency of 91.59 per cent was found at 20° inclination angle of drum and 70 rpm speed of roller, while it was decreased to 84.27 per cent at an inclination angle of drum of 30° and 90 rpm of roller. This was because of decreased residential time in the clearance between roller and outer casing with increase in inclination angle of drum.

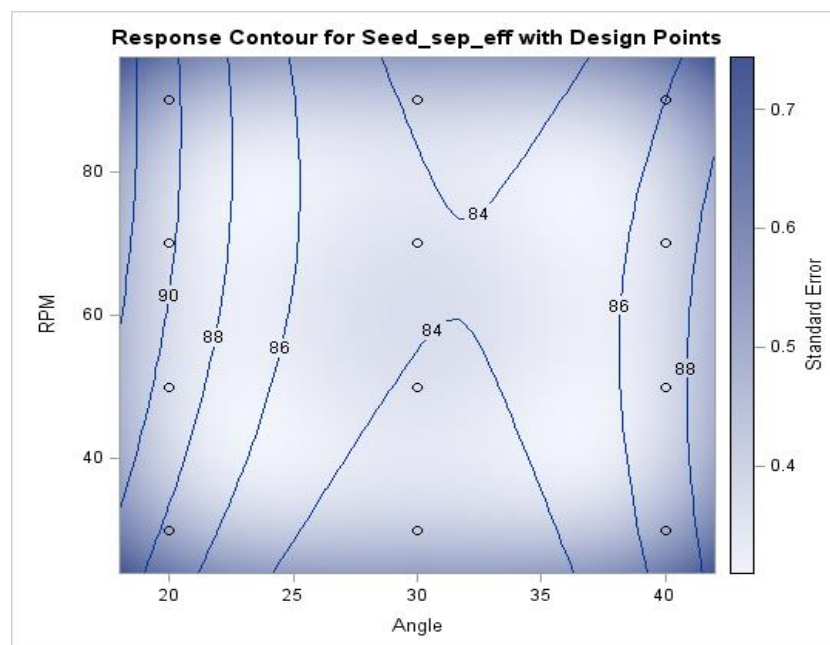


Fig. 4.2.7 Contour for seed separation efficiency

4.2.8 Response contour for flakes recovery

The recovery of the flakes was found to be depending mainly on the RPM of roller (central wire mounted roller), since the clearance between stainless steel wires cylinder and outer perforated casing varying from 7 mm at feed end to 2 mm at the discharge end.

It was observed that the flakes recovery was increasing with increase in inclination angle of drum and was decreasing with increase in RPM of roller (Fig. 4.2.8). The maximum flakes recovery of 81.05 per cent was found for a roller speed of 30 rpm and 30° inclination angle of drum, whereas minimum flakes recovery of 64.80 per cent was for a speed of 90 rpm and 20°

inclination angle of drum. The decrease in flakes recovery was due to increased momentum and inertial forces resulting in more impact action for squeezing out the pulp-flakes.

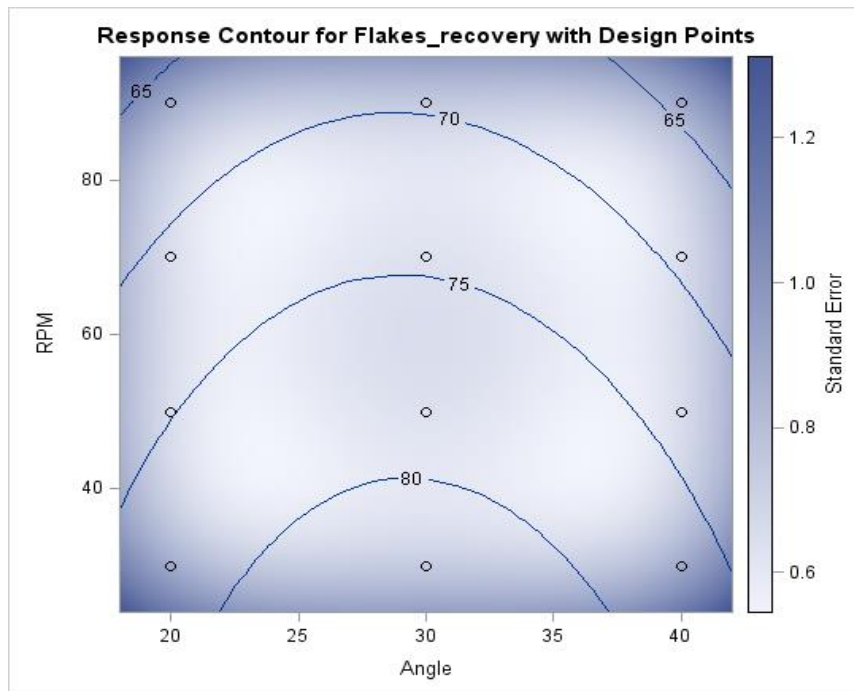


Fig. 4.2.8 Contour map for flakes recovery

4.2.9 Response contour for working capacity and seed separation efficiency

Response contours for working capacity and seed separation efficiency was analysed by SAS 9.1 and shown in Fig. 4.2.9. As per the analysis, the best combination of RPM of roller and inclination angle of drum for obtaining optimum working capacity and seed separation efficiency is 70 rpm and 42°, respectively. The optimum value of working capacity and seed separation efficiency is 80 kg/h and 88 per cent, respectively.

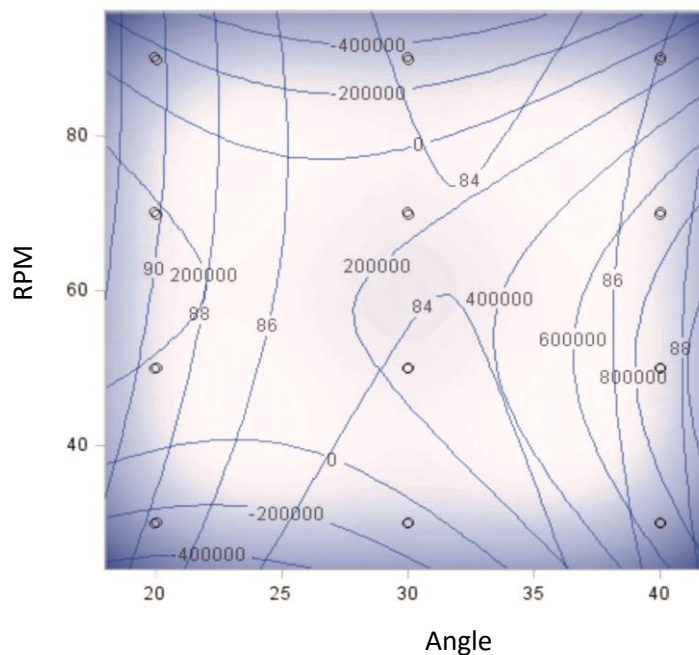


Fig. 4.2.9 Contour map for working capacity and seed separation efficiency

4.2.10 Response contour for working capacity and core recovery

The working capacity and core recovery were mainly found to be depending upon RPM of roller and inclination angle of drum. The response contours map of working capacity and core recovery was shown in Fig. 4.2.10. The optimum value of working capacity and core recovery is 60 kg/h and 85 per cent, respectively. As per the response contours map, the best combination of RPM of roller and angle of inclination of drum for obtaining optimum working capacity and core recovery is 77 rpm and 40°, respectively.

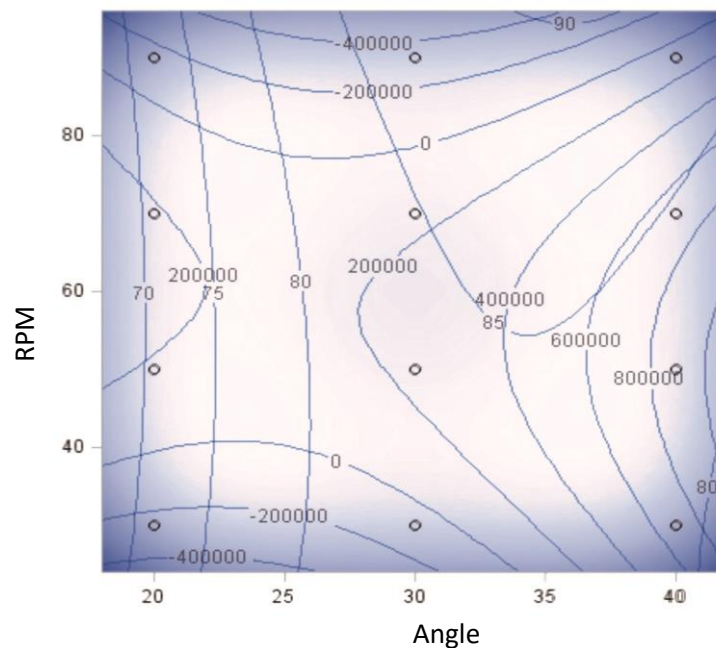


Fig. 4.2.10 Contour map for working capacity and core recovery

4.2.11 Response contour for working capacity and flakes recovery

As per the response contours for working capacity and flakes recovery as shown in Fig. 4.2.11, the working capacity and flakes recovery were increasing with increase in inclination angle of drum. However, it was observed that working capacity was increasing with increase in RPM of roller, while flakes recovery was decreasing with increase in RPM of roller. As per the response contours for optimum working capacity and flakes recovery, the best combination of RPM of roller and angle of inclination of drum is 48 rpm and 40°, respectively. The optimum value of working capacity and flakes recovery is 80 kg/h and 75 per cent, respectively.

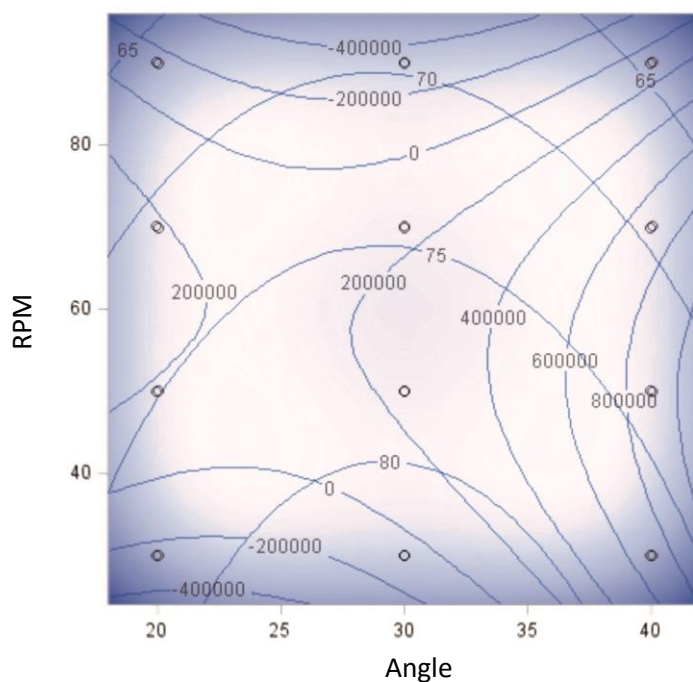


Fig. 4.2.11 Contour map for working capacity and flakes recovery

4.2.12 Response contour for seed separation efficiency and core recovery

The seed separation efficiency was decreasing while core recovery was increasing with increase in RPM of roller and angle of inclination of drum shown in Fig. 4.2.12. The optimum values of seed separation efficiency and core recovery as shown in response contours are 86 per cent and 80 per cent, respectively. The obtaining best combination of RPM of roller and inclination angle of drum is 70 rpm and 26°, respectively of said response contours of seed separation efficiency and core recovery.

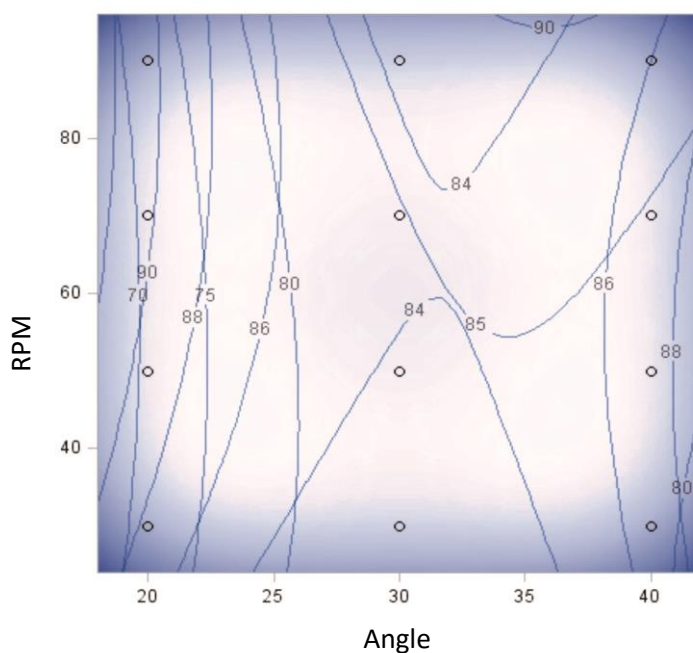


Fig. 4.2.12 Contour map for seed separation efficiency and core recovery

4.2.13 Response contour for seed separation efficiency and flakes recovery

The response contours for seed separation efficiency and flakes recovery was shown in Fig. 4.2.13. The seed separation efficiency was decreasing with increase in inclination angle of drum and flakes recovery was increasing with increase in inclination angle of drum. However, the seed separation efficiency and flakes recovery were decreasing with increase in RPM of roller. As per the response contours, the best combination of RPM of roller and inclination angle of drum for obtaining optimum seed separation efficiency and flakes recovery is 40 rpm and 27°, respectively. The optimum value of seed separation efficiency and flakes recovery is 84 per cent and 80 per cent, respectively of said combination of RPM of roller and inclination angle of drum.

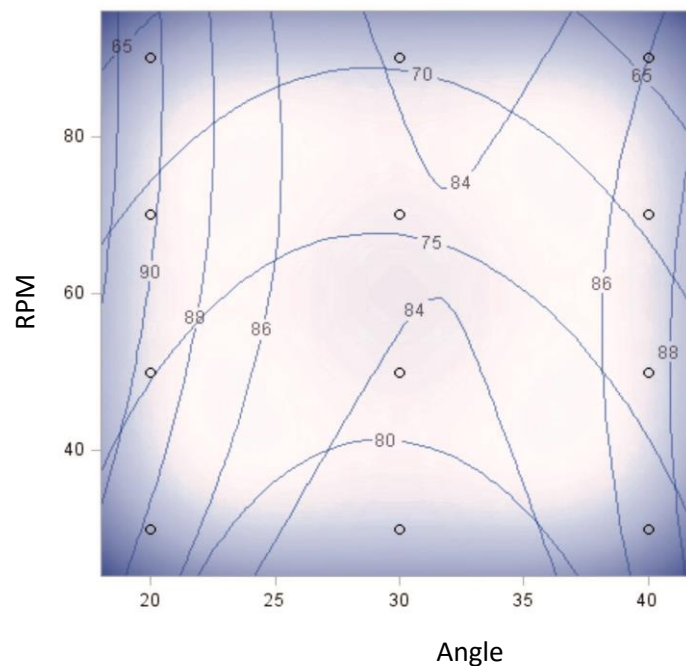


Fig. 4.2.13 Contour map for seed separation efficiency and flakes recovery

4.2.14 Response contour for core recovery and flakes recovery

The Fig. 4.2.14 shows the response contours map for core recovery and flakes recovery of custard apple pulp- flakes extractor. The core recovery was increasing with increase in RPM of roller and flakes recovery was decreasing with increase in RPM of roller. However, the core recovery and flakes recovery were increasing with increase in inclination angle of drum. The optimum value of core recovery and flakes recovery is 80 per cent and 80 per cent, respectively. The best combination of RPM of roller and inclination angle of drum for obtaining core recovery and flakes recovery is at 39 rpm and 26°, respectively.

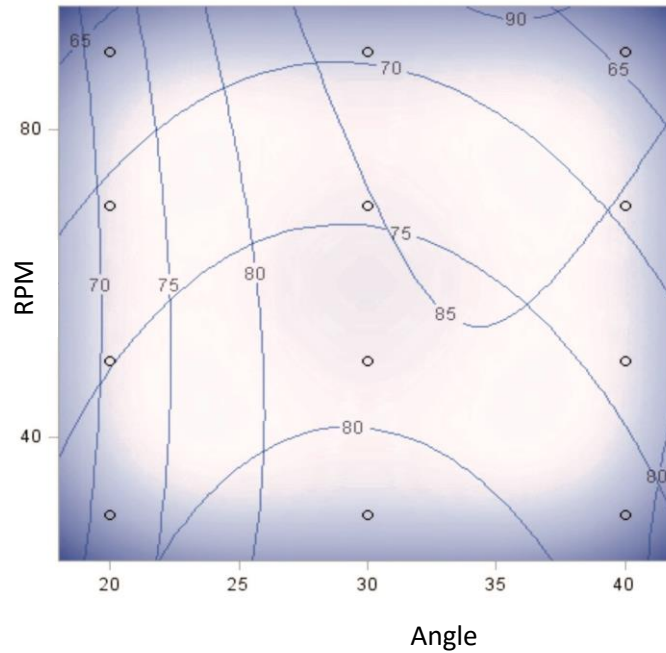


Fig. 4.2.14 Contour map for core recovery and flakes recovery

4.2.15 Response contour for core recovery, working capacity, seed separation efficiency and flakes recovery

The custard apple pulp-flakes extractor was tested for core recovery, working capacity, seed separation efficiency and flakes recovery by changing the RPM of roller as 30, 50, 70 and 90 rpm and inclination angle of drum varying from 20 to 40°. The response contours map shown in Fig. 4.2.15 was drawn for core recovery, working capacity, seed separation efficiency and flakes recovery while considering RPM of roller and inclination angle of drum

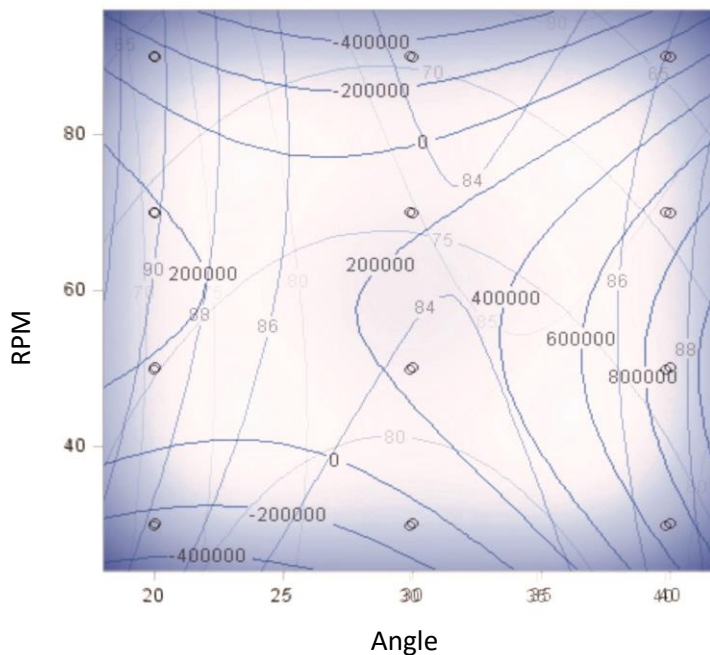


Fig. 4.2.15 Contour map for core recovery, working capacity, seed separation efficiency and flakes recovery

As per the response contours for core recovery, working capacity, seed separation efficiency and flakes recovery, the optimum value of core recovery, working capacity, seed separation efficiency and flakes recovery is 85 per cent, 80 kg/h, 86 per cent and 75 per cent, respectively. The best combination of RPM of roller and inclination angle of drum is 65 rpm and 38°, respectively for said optimum values of core recovery, working capacity, seed separation efficiency and flakes recovery.

The results obtained in the present investigation are in similar line with Kad *et al.* (2016) and Pawar (2012) for the testing of custard apple pulp-flakes extracting machine.

5. Summary and Conclusion

The present research entitled “Modification, development and performance evaluation of custard apple (*Annona squamosa* L.) pulp-flakes extractor” was conducted in three experiments on measurements of engineering properties of custard apple, modification of custard apple pulp-flakes extractor, to test the performance of custard apple pulp-flakes extractor. The results obtained are summarized under the following heads.

5.1 Summary

5.1.1 Engineering properties of custard apple

The physical and physico-morphological properties of uniformly selected twenty five custard apple fruits of Cv. Local were measured. The average length, breadth, thickness, size and sphericity of custard apple fruits were found to be 84.68 mm, 77.86 mm and 71.05 mm, 77.66 mm and 0.92, respectively. The average peel, carpellary pulp, gritty pulp and seeds were found to be 42.56 per cent, 36.74 per cent, 12.87 per cent and 7.92 per cent, respectively. The average weight of fruit and seed was 251.78 g and 0.33 g, respectively. The physical properties of randomly selected fifty custard apple seeds were measured. The average respective length, breadth and thickness of custard apple seeds was found to be 14.58 mm, 7.73 mm and 5.22 mm of a fresh seeds. Average seed size and average sphericity was 8.35 mm and 0.58. The bulk density, true density and porosity of seeds was found to be 648.28 kg/m³, 898.19 kg/m³ and 27.81 per cent. The results indicated that the angle of repose value for custard apple seed was 15.28°. The angle of repose of custard apple seeds with flakes and custard apple pulp/flakes was 36.05° and 45.77°, respectively while bulk density of custard apple seeds with flakes was 876.25 kg/m³. The rheological properties of custard apple seeds with flakes were also measured. The shearing force required for separating flakes from the seeds, pulp stickiness and viscosity of pulp was 2.71 N, 240.40 g and 50.65 cP, respectively.

5.1.2 Development and performance of custard apple pulp-flakes extractor

The machine was modified by using different engineering properties. The modification and development of custard apple pulp-flakes extractor was also carried out on the basis of convenience, experience, judgment, ease and simplicity of machining and availability of material. Considerable thrust was laid upon precision, accuracy and ease of operation of the machine. The method of trial and error was also used while designing the machine. The machine consists of constructional parts such as feeding hopper, central wire mounted roller with shaft, outer perforated casing, housing with seeds/pulp flakes outlet, seed outlet, pulp-flakes outlet, A.C. induction motor drive with gear box and frame on which all the parts were assembled.

The developed machine was evaluated for its efficiency in terms of core recovery, working capacity, flakes recovery and seed separation, with respect to roller speed and angle of inclination. The core recovery and working capacity were found to be increased with increase in roller speed and angle of inclination. Maximum core recovery of 87.57 per cent was found for roller speed of 90 rpm and angle of inclination of 40°. The minimum working capacity of 31.61 kg/h was recorded at speed of 30 rpm and 20° angle of inclination while maximum of 102 kg/h was for a roller speed of 90 rpm and 40° angle of inclination. It was observed that with increase in roller speed and angle of inclination, the working capacity increased. The seed separation efficiency decreased with increase in inclination angle of drum and roller speed. A seed separation efficiency of 86.86 per cent was found at 20° angle and 30 rpm while it decreased to 83.33 per cent at an inclination angle of 30° and 70 rpm. The flakes recovery increased with increase in inclination angle of drum and decreased with increase in speed of the roller. The maximum flakes recovery of 81.05 per cent was found for a roller speed of 30 rpm and 30° angle of inclination whereas minimum flakes recovery of 64.80 per cent was for a speed of 90 rpm and 20° angle of inclination angle of drum.

The optimum value of core recovery, working capacity, seed separation efficiency and flakes recovery was 85 per cent, 80 kg/h, 86 per cent and 75 per cent, respectively for 65 rpm of roller and 38° inclination angle of drum.

5.2 CONCLUSIONS

1. The average carpellary pulp, gritty pulp, seeds and peel in local cultivars of custard apple fruits was 36.74, 12.87, 7.92 and 42.56 per cent, respectively.
2. The optimum value of core recovery, working capacity, seed separation efficiency and flakes recovery was 85 per cent, 80 kg/h, 86 per cent and 75 per cent, respectively for 65 rpm of roller and 38° inclination angle of drum.

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Appendix - A

Table. Physical properties of custard apple fruit

Sr. No.	Weight of fruit, g.	Major axis (mm)	Intermediate axis (mm)	Minor axis (mm)	Size (mm)	Sphericity (fraction)
1.	204.06	75.09	74.15	66.27	71.72	0.95
2.	251.20	82.37	79.60	69.26	76.86	0.93
3.	297.38	96.90	88.47	80.66	88.43	0.91
4.	249.71	82.61	77.60	73.58	77.84	0.94
5.	171.11	70.00	68.40	62.49	66.88	0.95
6.	287.38	89.68	79.73	76.48	81.77	0.91
7.	253.04	80.11	78.50	70.80	76.36	0.95
8.	218.87	82.93	75.07	74.32	77.34	0.93
9.	248.11	79.11	76.40	72.94	76.11	0.96
10.	260.53	84.31	81.56	72.12	79.15	0.94
11.	229.03	83.46	77.22	62.11	73.70	0.88
12.	192.86	75.42	70.59	67.81	71.20	0.94
13.	214.80	81.70	72.65	68.29	74.01	0.90
14.	247.52	80.14	79.53	76.12	78.58	0.98
15.	192.88	71.25	69.59	69.37	70.06	0.98
16.	223.52	86.19	78.04	64.45	75.68	0.87
17.	306.58	86.20	75.98	66.80	75.91	0.88
18.	272.54	89.33	80.40	72.98	80.63	0.90
19.	418.82	96.72	85.30	83.11	88.18	0.91
20.	301.49	94.50	80.50	79.22	84.47	0.89
21.	321.09	105.42	92.60	68.16	87.30	0.83
22.	196.72	86.02	78.36	66.26	76.44	0.89
23.	278.12	89.52	81.72	77.50	82.76	0.92
24.	177.20	77.54	65.40	57.52	66.32	0.85
25.	280.03	90.40	79.09	77.66	82.19	0.91
Avg.	251.78	84.68	77.86	71.05	77.66	0.92

Appendix - B

Table B.1 Physico-morphological properties of custard apple fruit

Sr. No.	Weight of fruit (g)	Peel		Carpillary pulp		Gritty pulp		Number of seeds per fruit	Seeds per fruit		Weight Per seed (g)
		(g)	(%)	(g)	(%)	(g)	(%)		(g)	(%)	
1.	204.06	76.21	37.35	53.42	26.18	22.12	10.84	63	22.32	10.94	0.35
2.	251.20	84.81	33.76	81.12	32.29	38.41	15.29	69	25.86	10.29	0.37
3.	297.38	120.88	40.65	88.89	29.89	51.73	17.39	46	31.28	10.52	0.68
4.	249.71	106.03	42.46	74.84	29.97	29.08	11.64	75	26.82	10.74	0.36
5.	171.11	63.08	36.86	68.83	40.22	26.84	15.68	46	13.96	8.16	0.30
6.	287.38	138.24	48.10	98.21	34.17	30.26	10.53	68	19.67	6.84	0.29
7.	253.04	102.57	40.53	88.03	34.79	31.86	12.59	72	23.72	9.37	0.32
8.	218.87	81.45	37.21	87.51	39.98	32.09	14.66	49	10.12	4.62	0.21
9.	248.11	113.28	45.66	105.52	42.53	21.23	8.56	69	21.08	8.50	0.30
10.	260.53	122.80	47.13	82.96	31.84	31.57	12.11	58	13.12	5.03	0.23
11.	229.03	78.30	34.19	65.26	28.49	36.73	16.04	60	20.34	8.88	0.34
12.	192.86	76.45	39.64	53.94	27.97	28.45	14.75	63	18.68	9.68	0.29
13.	214.80	79.30	36.92	89.21	41.53	34.39	16.01	58	13.21	6.15	0.23
14.	247.52	103.96	42.00	82.13	33.18	28.94	11.69	66	21.82	8.81	0.33
15.	192.88	61.94	32.11	65.35	33.88	24.46	12.68	69	22.13	11.47	0.32
16.	223.52	118.70	53.10	118.70	53.10	31.54	14.11	37	13.09	5.86	0.35
17.	306.58	148.10	48.31	141.10	46.02	35.07	11.44	48	19.30	6.29	0.40
18.	272.54	130.03	47.71	130.03	47.71	32.68	11.99	55	21.60	7.92	0.39
19.	418.82	156.10	37.27	156.10	37.27	70.01	16.72	85	32.46	7.75	0.38
20.	301.49	132.28	43.87	132.28	43.87	44.78	14.85	75	22.68	7.52	0.30
21.	321.09	141.15	43.95	139.02	43.30	27.02	8.41	82	29.09	9.06	0.35
22.	196.72	92.71	47.13	73.50	37.36	19.50	9.91	19	6.90	3.51	0.36
23.	278.12	141.20	50.77	95.15	34.21	31.29	11.25	65	21.02	7.56	0.32
24.	177.20	85.90	48.48	63.52	35.85	20.56	11.60	39	9.86	5.56	0.25
25.	280.03	137.02	48.93	92.12	32.90	30.63	10.94	61	19.63	7.01	0.32
Avg.	251.78	107.70	42.56	93.07	36.74	32.45	12.87	59.88	19.99	7.92	0.33

Table B.2 Physico-morphological properties of custard apple fruit

Sr. No.	Total weight of pulp (g)	Fruit to pulp ratio	Pulp to seed ratio
1.	75.54	2.70	3.38
2.	119.53	2.10	4.62
3.	140.62	2.11	4.49
4.	103.92	2.40	3.87
5.	95.67	1.79	6.85
6.	128.47	2.24	6.53
7.	119.89	2.11	5.05
8.	119.6	1.83	11.82
9.	126.75	1.96	6.01
10.	114.53	2.27	8.73
11.	101.99	2.24	5.01
12.	82.39	2.34	4.41
13.	123.6	1.74	9.36
14.	111.07	2.23	5.09
15.	89.81	2.15	4.06
16.	150.24	1.49	11.48
17.	176.17	1.74	9.13
18.	162.71	1.67	7.53
19.	226.11	1.85	6.96
20.	177.06	1.70	7.81
21.	166.04	1.93	5.71
22.	93	2.11	13.48
23.	126.44	2.20	6.01
24.	84.08	2.11	8.53
25.	122.75	2.28	6.25
Avg.	125.52	2.05	6.89

Appendix - C

Table. Linear dimensions, seed size and sphericity of custard apple seeds

Sr. No.	Length (mm)	Breath (mm)	Thickness (mm)	Seed size (mm)	Sphericity (mm)
1.	15.56	7.56	4.67	8.19	0.53
2.	15.68	7.51	5.04	8.40	0.53
3.	16.12	6.99	4.76	8.12	0.50
4.	15.98	5.85	5.28	7.90	0.49
5.	12.96	8.87	5.23	8.44	0.65
6.	14.14	7.60	5.08	8.17	0.58
7.	15.11	7.27	4.45	7.88	0.52
8.	15.97	7.30	4.50	8.06	0.50
9.	15.40	7.74	5.23	8.54	0.55
10.	16.50	8.12	5.08	8.80	0.53
11.	14.12	7.59	5.24	8.25	0.58
12.	15.39	8.71	5.08	8.80	0.57
13.	16.76	7.58	5.04	8.62	0.51
14.	15.73	7.01	5.57	8.50	0.54
15.	17.03	6.70	4.70	8.12	0.48
16.	13.80	7.83	4.27	7.73	0.56
17.	14.54	7.53	5.36	8.37	0.57
18.	14.71	7.09	5.28	8.20	0.56
19.	15.55	7.43	5.56	8.63	0.55
20.	15.62	6.69	5.07	8.09	0.52
21.	14.96	7.13	4.60	7.89	0.53
22.	15.45	7.71	4.62	8.19	0.53
23.	14.87	7.86	4.57	8.11	0.54
24.	14.12	7.21	4.99	7.98	0.56
25.	14.87	8.18	4.98	8.46	0.57
26.	16.06	7.74	4.92	8.49	0.53
27.	16.20	6.99	4.73	8.12	0.50
28.	13.95	7.57	4.90	8.03	0.57

29.	12.15	7.53	4.97	7.69	0.63
30.	11.82	8.58	4.90	7.92	0.67
31.	15.32	8.89	5.86	9.27	0.60
32.	14.35	7.88	5.94	8.76	0.61
33.	12.87	7.15	5.99	8.20	0.64
34.	13.16	8.87	5.83	8.79	0.67
35.	14.88	8.86	5.57	9.02	0.61
36.	12.76	8.71	6.02	8.75	0.68
37.	15.49	8.72	5.06	8.81	0.57
38.	12.69	7.56	4.86	7.75	0.61
39.	14.53	7.98	5.33	8.52	0.59
40.	13.21	7.45	4.87	7.82	0.59
41.	13.78	8.54	5.76	8.78	0.64
42.	14.71	7.16	5.58	8.38	0.57
43.	13.40	8.22	5.13	8.27	0.62
44.	14.02	8.71	6.06	9.04	0.64
45.	11.06	7.08	6.04	7.79	0.70
46.	12.54	7.45	6.07	8.28	0.66
47.	14.39	7.82	5.89	8.72	0.60
48.	16.63	8.36	6.33	9.58	0.58
49.	17.27	7.33	5.53	8.88	0.51
50.	10.97	8.25	4.68	7.51	0.68
Avg.	14.58	7.73	5.22	8.35	0.58

Appendix - D

Table D.1 Measurement of bulk density of custard apple seeds

Sr. No.	Weight of seeds (g)	Volume of measuring cylinder (mL)	Bulk density (kg/m ³)
1.	323.16	500	646.32
2.	319.96	500	639.92
3.	323.00	500	646.00
4.	310.68	500	621.36
5.	330.25	500	660.50
6.	326.86	500	653.72
7.	331.26	500	662.52
8.	329.42	500	658.84
9.	333.58	500	667.16
10.	326.64	500	653.28
11.	334.66	500	669.32
12.	322.14	500	644.28
13.	321.65	500	643.30
14.	330.01	500	660.02
15.	298.86	500	597.72
Average bulk density			648.28

Table D.2 Measurement of true density of custard apple seeds

Sr. No.	Initial volume of toluene (mL)	Weight of seeds (g)	Volume of toluene displaced (mL)	True density (kg/m³)
1.	200	20	19.52	888.22
2.	200	20	19.72	879.21
3.	200	20	18.92	916.38
4.	200	30	28.84	901.77
5.	200	30	28.46	913.81
6.	200	30	29.00	896.79
7.	200	40	38.20	907.75
8.	200	40	39.01	888.90
9.	200	40	37.96	913.49
10.	200	50	48.85	887.31
11.	200	50	48.72	889.68
12.	200	50	47.56	911.38
13.	200	60	58.78	884.89
14.	200	60	58.10	895.25
15.	200	60	57.92	898.03
Average true density				898.19

Table D.3 Measurement of porosity of custard apple seeds

Sr.No.	True density (kg/m³)	Bulk density (kg/m³)	Porosity (%)
1.	888.22	646.32	27.23
2.	879.21	639.92	27.22
3.	916.38	646.00	29.51
4.	901.77	621.36	31.10
5.	913.81	660.50	27.72
6.	896.79	653.72	27.10
7.	907.75	662.52	27.02
8.	888.90	658.84	25.88
9.	913.49	667.16	26.97
10.	887.31	653.28	26.38
11.	889.68	669.32	24.77
12.	911.38	644.28	29.31
13.	884.89	643.30	27.30
14.	895.25	660.02	26.28
15.	898.03	597.72	33.44
Average porosity			27.81

Table D.4 Measurement of angle of repose of custard apple seeds

Sr.No.	Hight of the cone/ heap (mm)	Diameter of the base of cone/heap (mm)	Angle of repose (°)
1.	23.50	90	15.14
2.	24.00	90	15.47
3.	23.00	90	14.81
4.	23.30	90	15.01
5.	23.00	90	14.81
6.	24.50	90	15.80
7.	24.30	90	15.67
8.	23.30	90	15.01
9.	24.00	90	15.47
10.	23.50	90	15.14
11.	24.00	90	15.47
12.	24.50	90	15.80
13.	23.50	90	15.14
14.	23.30	90	15.01
15.	24.00	90	15.47
Average angle of repose			15.28

Appendix - E

Table E.1 Measurement of bulk density of custard apple seeds with flakes

Sr. No.	Weight of seeds (g)	Volume of measuring cylinder (mL)	Bulk density (kg/m ³)
1.	438.40	500	876.80
2.	436.80	500	873.60
3.	437.48	500	874.96
4.	437.84	500	875.68
5.	438.75	500	877.50
6.	439.12	500	878.24
7.	440.02	500	880.04
8.	439.54	500	879.08
9.	438.10	500	876.20
10.	435.60	500	871.20
11.	440.00	500	880.00
12.	437.75	500	875.50
13.	438.52	500	877.04
14.	438.48	500	876.96
15.	435.45	500	870.90
Average bulk density			876.25

Table E.2 Measurement of angle of repose of custard apple seed with flake

Sr. No.	Stainless steel plate length (cm)	Height of the plate (cm)	Angle of repose (θ°)
1.	22.50	12.70	34.38
2.	22.50	13.20	35.94
3.	22.50	14.10	38.82
4.	22.50	13.50	36.89
5.	22.50	14.00	38.50
6.	22.50	12.50	33.77
7.	22.50	13.90	38.17
8.	22.50	12.50	33.77
9.	22.50	12.30	33.16
10.	22.50	12.90	35.00
11.	22.50	14.10	38.82
12.	22.50	12.90	35.00
13.	22.50	13.40	36.57
14.	22.50	12.90	35.00
15.	22.50	13.50	36.89
Average angle of repose			36.05

Appendix - F

Table: Measurement of angle of repose of custard apple pulp/flakes

Sr. No.	Stainless steel plate length (cm)	Height of the plate (cm)	Angle of repose (θ°)
1.	22.50	16.40	46.82
2.	22.50	15.80	44.63
3.	22.50	16.10	45.71
4.	22.50	16.30	46.45
5.	22.50	15.40	43.21
6.	22.50	16.70	47.95
7.	22.50	15.80	44.63
8.	22.50	16.50	47.19
9.	22.50	16.90	48.71
10.	22.50	16.50	47.19
11.	22.50	16.70	47.95
12.	22.50	15.50	43.56
13.	22.50	14.90	41.49
14.	22.50	16.00	45.35
15.	22.50	16.10	45.71
Average angle of repose			45.77

8. VITAE

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MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)
IN
PROCESS AND FOOD ENGINEERING
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