DEVELOPMENT AND EVALUATION OF A JACKFRUIT PEELER CUM CORER

by

HAREESHA T SHIDENUR
(2014-18-116)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING
(Agricultural Processing and Food Engineering)
Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR - 679573, MALAPPURAM
KERALA, INDIA

2016

DECLARATION

I hereby declare that this thesis entitled **"Development and evaluation of a jackfruit peeler cum corer"** is a *bonafide* record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Tavanur : **HAREESHA T SHIDENUR**

Date : 20-10-2016 **(2014-18-116)**

Dr. Santhi Mary Mathew
Professor and Head
Department of Food & Agricultural Process Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur, Malappuram, Kerala.

CERTIFICATE

Certified that this thesis entitled **"Development and evaluation of a jackfruit peeler cum corer"** is a *bonafide* record of research work done independently by **Mr. Hareesha T Shidenur** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Tavanur

Dr. Santhi Mary Mathew
(Chairman, Advisory Committee)

CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. Hareesha T Shidenur (2014-18-116)** a candidate for the degree of Master of Technology in Agricultural Engineering majoring in Agricultural Processing and Food Engineering agree that the thesis entitled **"Development and evaluation of a jackfruit peeler cum corer"** may be submitted by **Mr. Hareesha T Shidenur (2014-18-116)** in partial fulfillment of the requirement for the degree.

Dr. Santhi Mary Mathew
Professor and Head
Dept. of Food & Agricultural Process Engineering
Kelappaji College of Agricultural Engineering & Technology, Tavanur
(Chairman)

Dr. Prince M.V.
Professor
Dept. of FAPE
KCAET, Tavanur
(Member)

Dr. Sudheer K.P.
Professor & Project Coordinator
Centre of Excellence in Post-harvest Technology
Dept. of FAPE
KCAET, Tavanur
(Member)

Dr. Jayan P.R.
Professor and Head
Department of FPME
KCAET, Tavanur
(Member)

Dr. M.R. Manikantan
Senior Scientist (APE)
PB & PHT Division
CPCRI, Kasaragod
EXTERNAL EXAMINER

06/10/16

Acknowledgement

ACKNOWLEDGEMENT

This thesis is the end of my journey in obtaining Master's degree. I have not travelled in vacuum in this journey. My research has been on track and reached completion with the support and encouragement of numerous people especially my well-wishers. It is a pleasant task to express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me.

I would like to give my first thanks to almighty **God** *and my* **Parents** *as without their mercy, accomplishment of my work and preparation of this manuscript would have not been possible.*

I am immensely expressing my scrupulous gratitude to **Dr. Santhi Mary Mathew,** *Professor and Head, Dept. of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur, my guide, for her esteemed stewardship and enabling guidance in successful completion of this work.*

It is my pleasure to pay tribute to **Dr. Hajilal M.S.,** *Dean, K.C.A.E.T, Tavanur, for his advice and guidance rendered during this study.*

I would like to express my heartfelt gratitude to **Dr. Sivaswami M.,** *former Dean, K.C.A.E.T, Tavanur, for his interest and kind advice given to me at all stages of my study.*

It gives me immense pleasure to express my sincere thanks to the members of my advisory committee **Dr. Prince M.V.,** *Professor, Dept. of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur,* **Dr. Sudheer K.P.,** *Professor, Dept. of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur and* **Dr. Jayan P.R.,** *Professor and Head, Dept. of Farm Power Machinery and Energy, K.C.A.E.T, Tavanur for their valuable counsel, note-worthy guidance and cordial co-operation during the course of investigation.*

I place my special thanks to, ***Dr. Sasikala D.,*** *Professor, Dept. of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur,* ***Er. Shivaji K.P.,*** *Assistant Professor, Dept. of Farm Power Machinery and Energy, K.C.A.E.T, Tavanur and* ***Dr. Rajesh G.K.,*** *Associate Professor,* ***Er. George Mathew.,*** *Associate Professor, and* ***Mrs. Sreeja R.,*** *Assistant Professor, Dept. of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur, for their valuable guidance, profound suggestions and constant encouragement and advice throughout the project work.*

I would like to acknowledge the valuable help rendered by ***Dr. Arun Prasath.,*** *Teaching Assistant, Dept. of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur, for his sincere help, support and co-operation for the completion of my research project report.*

I wish to express my gratitude to ***Dr. Krishnan S.,*** *Professor, College of Horticulture, Vellanikkara for explaining me the statistical techniques required for the study.*

I am immensely thankful to ***Dr. Pandiselvam R., Dr. Anjineyalu K., Dr. Riju M.C., Er. Amaljith., Er. Sariga S.,*** *Teaching assistant, K.C.A.E.T, Tavanur, for their esteemed help and support offered during the study.*

I express my profound sense of gratitude to ***Mrs. Jojitha., Er. Reshma., Mrs. Vimitha., Mr. Radhakrishnan, M.V., Mr. Sreenish,*** *for their immense help.*

My heartfelt gratitude to ***Mr. Manohar Krishna., Mr. Lenin.,*** *and all other workshop staff, cannot be captured in words for their co-operation and assistance during the fabrication work.*

It is my pleasure to offer whole hearted thanks to Ph.D. scholars ***Er. Sankalpa K.B.*** *and* ***Er. Rana Salva*** *for their valuable suggestions, constant encouragement and moral support shown throughout my study.*

My completion of this project could not have been accomplished without the support of my classmates especially, ***Seema, Srikanth, Madhukumar, Chandan, Saranya, Bhavya, Sagarika, Dayanand, Lakshminarayana, Deepak, Salsan and Arjun*** *for their suggestion and invaluable help during my study.*

I express my thanks to all the faculty ***members of Library****, KCAET, Tavanur for their ever willing help and cooperation. I express my sincere thanks and gratitude to* ***Kelappaji College of Agricultural Engineering & Technology*** *for giving me an opportunity to undergo my P.G studies and* ***Kerala Agricultural University*** *for providing me the KAU merit scholarship and for having proffered me a chance to study in this institution.*

I am greatly indebted to my parents ***Smt. Sunanda*** *and* ***Sri. Tirakappa*** *for their blessings, prayers, and support, without which I could not have completed this work*

One last word; since it is practically impossible to list all the names who have contributed to my work, it seems proper to issue a blanket of thanks for those who helped me directly or indirectly during the course of study.

Hareesha T Shidenur

Dedicated to

My parents

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

Abbreviations/ Notations		Description
MT	:	Metric tonne
%	:	Per cent
et al.	:	And others
ha	:	Hectare
kg	:	Kilogram
m	:	Meter
s		Second
viz.	:	Namely
APAARI	:	Asia-Pacific Association of Agricultural Research Institutions
g	:	Gram
mg	:	Milligram
kJ	:	Kilojoules
mm	:	Millimeter
cm	:	Centimeter
kg	:	Kilogram
/	:	Per
min	:	Minute
kJ/m^2	:	Kilo joules per meter square
m/s	:	Meter per second

m/min	:	Meter per minute
N	:	Newton
rpm	:	Revolutions per minute
Fig.	:	Figure
kg/h	:	Kilogram per hour
etc.	:	Etcetera
h	:	Hour
K.C.A.E.T	:	Kelappaji College of Agricultural Engineering and Technology
U.S	:	United states
FOS	:	Factor of safety
kN	:	Kilonewton
ID	:	Inner diameter
OD	:	Outer diameter
SS	:	Stainless steel
MS	:	Mild steel
hp	:	Horsepower
Rs.	:	Rupees
$\geq$	:	Greater than or equal to
$\leq$	:	Lesser than or equal to
$\pm$	:	Plus or minus
μ	:	Mu
$=$	:	Equal to
η	:	Eta
λ	:	Lambda

#	:	Hash
ie.	:	That is
UTM	:	Universal testing machine
ANOVA	:	Analysis of variance
CAD	:	Computer aided design
CRD	:	Completely randomized design
IPGRI	:	International plant genetic resource institute
kWh	:	Kilowatt hour
Sl. No.	:	Serial number
SD	:	Standard deviation

Introduction

CHAPTER I

INTRODUCTION

India, endowed with varied agro-climate, is highly conducive for growing numerous horticultural crops. The fruit production during 2013-14 was 88.97 MT and for vegetables was 162.897 MT. This accounts for nearly 13.6% and 14% of the country's share in the world production (National Horticulture Board, 2015). Even though. India is the largest producer of fruits and vegetables after China, it processes only less than 2.5% of the produce compared to 70-83% in advanced countries (Akhila and Shareena, 2009). Due to lack of cold chain facility, unavailability of temperature controlled vehicle, improper packaging and lack of proper processing techniques, nearly 25-30% of produce is wasted every year and are not efficiently utilized (Rais and Sheoran, 2015). To avoid these problems, we need technological development and diversification of these valuable fruits which is most important in filling the ever increasing demand-supply gap.

Jackfruit (*Artocarpus Heterophyllus*) belongs to the family *Moraceae* and is a popular and important fruit, very underutilized. It is native fruit of India, now widely cultivated throughout the tropical countries in both the hemispheres such as India, Bangladesh, Nepal, Sri Lanka, Vietnam, Thailand, Malaysia, Indonesia and Philippines. India is the largest producer of jackfruit followed by Bangladesh and Thailand (Kittur *et al.*, 2015). The trees populate north-eastern states like Assam, Tripura, Bihar, Uttar Pradesh, the foothills of the Himalayas and South Indian states of Kerala, Tamil Nadu and Karnataka. The total cultivated area and production in India during 2013-14 was 1,58,000 ha and 1.573 MT respectively (National Horticulture Board, 2015). In South India, the annual production of jackfruit ranks next to the mango and banana. In Kerala, jackfruit is cultivated in an area of about 90,225 ha; occupied 28% of the fresh fruits category with a production of about 294 million number per year (Agricultural Statistics, 2015).

Jackfruit, is an organic fruit cultivated as a homestead tree without any management practices. There are several varieties of jackfruit available, which differ widely in size, shape and taste. The values of fruit weight, length, and diameter in the different accessions of Kerala ranging from 3.95-20.13 kg, 28.66-52.66 cm and 18.46-30.50 cm respectively (Gomez *et al.*, 2015). Also, it constitutes three main parts, namely bulb, seed and rind and their proportion was 30%, 12% and 50-55%, respectively (Ranganna, 2014).

The jackfruit is a nutritious fruit rich in dietary fiber, carbohydrates, calcium, and iron and also vitamin A, B and C. (Crane *et al.*, 2005). It helps to cure ulcers and indigestion; also having anti-cancer properties. Apart from table purpose, the ripen fruits are used for making canned products, nectar, preserve, jam, jelly, squash, fruit bar and candy.

Nowadays, demand for jackfruit is increasing day by day owing to its availability, sweetness and nutritional composition. Sensitized growers and entrepreneurs focus more on development of value added products. The increasing demand of jackfruit can be regulated by increasing production and also by varietal improvement in species and method of propagation. In spite of its huge production, the utilization as food material is quite negligible, less than 40% and the remaining is going as waste. The traditional method of peeling and coring is done by cutting the fruit into two halves lengthwise using a knife, which is a time consuming process and causes drudgery. Moreover, the latex of this fruit is also hindering during the separation of the fruit bulb for consumption. The tedium in manual processing is a major reason for the underutilization of the fruit. Thus, effective mechanization in processing is a need of the hour.

The above scenario urgently demands for the development of a mechanical tool or machine for peeling, coring and cutting of whole jackfruit. This development will reduce the wastage of major quantity of jackfruit and also helps in preparation of primary processed products that can be used for production of other products. The developed tool can be easily operated by women and unskilled labour, so it also increases the commercial utilization of jackfruit. In this context, the present study on development and evaluation of a jackfruit peeler cum corer was formulated with the following objectives.

1. To study selected physical and mechanical properties of jackfruit.
2. To develop a mechanical tool for cutting, coring and removal of bulb from jackfruit.
3. To evaluate the performance of the developed mechanical tool.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter sets out to identify and critically analyse all the previously published literature with regard to the general information of jackfruit, engineering properties of different produces, development and evaluation of peeler and slicer machines and the material selection for equipment fabrication.

2.1 Jackfruit (*Artocarpus Heterophyllus L.*)

Jackfruit is indigenous and grows wild in the rain forests of the Western Ghats of India. The name originated from Malayalam name Chakka, other Indian names of the fruit are: Halasu (Kannada), Panasa (Sanskrit and Telugu), Kathal (Hindi), Phanas (Marathi) and Pala (Tamil) (Pradeepkumar and Kumar, 2008). Jackfruit is popularly known as poor man's fruit in the Eastern and Southern parts of India with significant contribution to the low income families as a good source of vitamins, minerals and calories (Rahman *et al.*, 1995). In Kerala, this fruit is underutilised considering its large scale production, meagre utilization in processing sector and huge post-harvest losses.

2.1.1 Botanical aspects and distribution

Jackfruit tree is an evergreen tree, around 10-15 m tall with oval shaped dark green leaves. It is a long lived tree having a life span of 60-70 years and contains sticky white latex in all parts of fruit. The flowering twigs are borne primarily on the trunk and main branches. Jackfruit tree is monoecious, male and female flowers are borne separately on the same tree. The composite fruit may be large as 20 kg or more. Fruit is the primary economic product of tree and used in both stages when mature and immature (Nachegowda *et al.*, 2014).

Jackfruit is made up of three regions *viz.*, the lower fleshy edible region, commonly called as the bulb; the middle fused region, that forms the rind of the syncarp and the upper free and horny non-edible region commonly known as the spikes. Except for the thorny outer bark all parts of the fruit are edible (Prakash *et al.*, 2009).

The jackfruit cultivated in area of 1,02,552 ha, of which an estimated 1,00,000 trees are grown in back yards and as intercrop in other commercial crops. Kerala has the largest area of jackfruit cultivation of about 97,540 ha and production around 348 million fruits (APAARI, 2012).

Fig. 2.1 shows that, the cultivated area of jackfruit in Kerala during (2013-14) was 90,225 ha and jackfruit was widely cultivated in Idukki (14636 ha), Kozhikode (9805 ha) and Kannur (8400 ha) districts and stand 1st, 2nd and 3rd positions with 16%, 11% and 9% of area, respectively. Gross production of jackfruit in Kerala is 294 million fruits with Idukki district holding the top most position (60 million) followed by Kannur district (27 million) (Table 2.1).

2.1.2 Varieties

According to Elevitch and Manner (2006) the variation in species is based on tree size and structure, leaf and fruit form, age of fruit bearing, fruit size, shape, color and texture of the edible pulp.

Koozha and Varikka are the two main varieties of jackfruits available in Kerala. Jackfruit having thin, fibrous and mushy edible pulp which is very sweet and emitting strong odour is called Koozha. But Varikka is thick, firm, crisp and has less fragrant pulp. Thamara chakka, Nadavalam varikka, Vakathanam varikka, Muttom varikka, Aathimathuram koozha, Ceylon varikka and Thenga varikka are the main jackfruit varieties in Kerala. Konkan prolific, Ceylon jack, Hybrid jack, Burliar-1, PLR-1, PPI-1 are few important varieties introduced from the various organizations (Priya *et al.*, 2014).

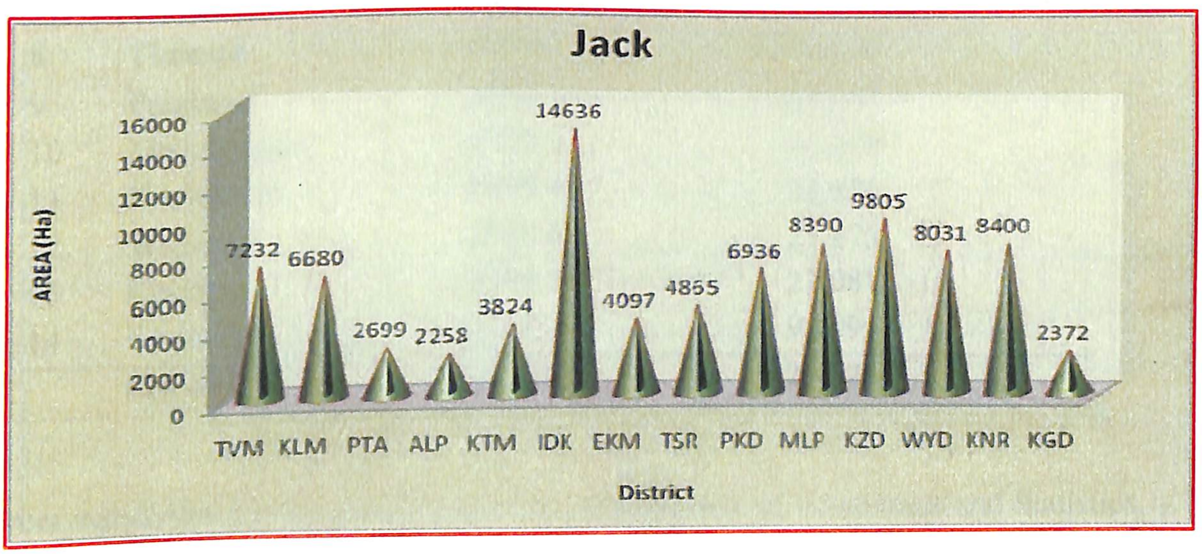

Fig. 2.1 District-wise cultivated area of jackfruit in Kerala

Source: Agricultural Statistics (2013-2014) - Department of Economics and Statistics, Govt. of Kerala (2015)

Table 2.1 District-wise area and production of jackfruit in Kerala

Sl. No.	Name of District	Area of cultivation (ha)	Production (Million Number)
1	Thiruvananthapuram	7232.43	25.821
2	Kollam	6680.00	23.136
3	Pathanamthitta	2698.54	8.968
4	Alappuzha	2258.3	5.627
5	Kottayam	3824.06	14.728
6	Idukki	14635.92	60.307
7	Ernakulam	4097.46	14.35
8	Thrissur	4864.5	15.636
9	Palakkad	6936.21	22.697
10	Malappuram	8390.12	22.278
11	Kozhikode	9805.43	23.121
12	Wayanad	8030.6	21.275
13	Kannur	8399.59	27.081
14	Kasaragod	2371.79	9.209
	State total	**90224.95**	**294.234**

Source: Agricultural Statistics (2013-2014) - Department of Economics and Statistics, Govt. of Kerala (2015)

2.1.3 Harvesting

In Asia, depending on the climatic region, fruits ripen mainly from March-June, April-September or June-August and for some offseason crops from September-December (Morton, 1987).

Jackfruits mature 3-8 months from flowering. When mature, there is usually a change of fruit colour from light green to yellow-brown, spines are closely spaced, yield to moderate pressure and there is a dull hollow sound when the fruit is tapped (Sharma *et al.*, 1997).

2.1.4 Nutritional composition

Jagadeesh *et al.* (2007) studied the chemical composition of bulbs. The study revealed that, bulbs contain total soluble solid (TSS), acidity, sugars, starch and carotenoid in jackfruit types. Also, it is a nutritious fruit, rich in vitamin A, vitamin B complex, vitamin C, potassium, calcium, iron, proteins and carbohydrates.

Jackfruits have high nutritional and medicinal values. It can strengthen immune system, protect against cancer, aid in healthy digestion, helps to maintain a healthy eye and skin, help to boost energy, lowering high blood pressure, controls asthma, help to strengthen the bone, prevent anaemia and maintain a healthy thyroid Priya *et al.*, (2014).

Table 2.2 Nutritional composition of fresh jackfruit (per 100 g)

Composition	Young fruit	Ripe fruit	Seed
Water (g)	76.20-85.20	72.00-94.00	51.00-64.50
Protein (g)	2.00-2.60	1.20-1.90	6.60-7.04
Fat (g)	0.10-0.60	0.10-0.40	0.40-0.43
Carbohydrate (g)	9.40-11.50	16.00-25.40	25.80-38.40
Fibre (g)	2.60-3.60	1.00-1.50	1.00-1.50
Total sugars (g)	-	20.60	-

Vitamins

Vitamin A (IU)	30.00	175.00-540.00	10.00-17.00
Thiamine (mg)	0.05-0.15	0.03-0.09	0.25
Riboflavin (mg)	0.05-0.20	0.05-0.40	0.11-0.30
Vitamin C (mg)	12.00-14.00	7.00-10.00	11.00
Energy (kJ)	50.00-210.00	88.00-410.00	133.00-139.0

Minerals

Total minerals	0.90	0.87-0.90	0.90-1.20
Calcium (mg)	30.00-73.20	20.00-37.00	50.00
Magnesium (mg)	-	27.00	54.00
Phosphorus (mg)	20.00-57.20	38.00-41.00	38.00-97.00
Potassium (mg)	287.00-323.00	191.00-407.00	246.00
Sodium (mg)	3.00-35.00	2.00-41.00	63.20
Iron (mg)	0.40-1.90	0.50-1.10	1.50

Source: [Arkroyd *et al.* (1966), Narasimham, (1990), Gunasena *et al.* (1996), Azad, (2000) and Manjeshwar *et al.* (2011)].

2.1.5 Post harvest utility

Jackfruit is generally consumed as raw and refined form and less than 40% of fruit is utilized as a food material and the remaining is going waste because of tedious in manual processing and time consuming process. Moreover, the latex of this fruit is also causing some hindrance during the separation of the fruit bulbs for consumption are the major reason for the underutilized fruit.

2.2 Physical properties

The study of the physical properties of products is very important in the design of particular equipment and analysis of the behavior of the product during post-harvest operations (Sahay and Singh, 1994). It can increase the efficiency of processing equipment, especially for peeler and slicer. Knowledge of the physical properties like weight, length and diameter of the fruit, length and diameter of fruit core and fruit rind thickness are necessary for development of mechanical tool for jackfruit peeling, cutting and coring. The determination of physical properties of different fruits followed by various research workers were reviewed for the study.

2.2.1 Size

Size, generally refers to characteristics of an object which determines the space requirement within the limit and necessary for satisfactory description of the any solid object. The size of fruits is important in determining their suitability and understands the properties that may affect the design of machines. Researchers have used various techniques to investigate the dimensions of different produce and its experimental results are given below.

Singh and Shukla (1995) conducted the experiment on physical properties of potato *viz.*, length, breadth and thickness to develop a potato peeler. Vernier calipers were used for measuring these properties.

Owolarafe and Shotonde (2004) reported the physical properties required for the designing of an okra slicer, chopper and grater. The average fruit length, width and thickness were 54.60, 28.60 and 26.70 mm respectively.

Jha *et al.* (2006) studied the physical and mechanical properties of mango fruit to determine the maturity. In order to measure the fruit length, width and thickness digital vernier calipers (least count 2 mm) were used.

Rafiee *et al.* (2007) studied some of the physical properties of bergamot (*Citrus medica*) fruit by image processing technique to develop appropriate technologies for its processing. The fruit dimensions and projected areas were determined using a Win Area UT-06 system (Fig. 2.2) with sensitivity of 0.05 mm, where T, W and L are the minor, medium and major perpendicular dimensions of the fruit and P_T, P_L and P_W are projected area perpendicular to W, T and L, respectively (Fig. 2.3). The length, width and thickness of the fruit varied from 78.70 to 160 mm, 64.2 to 128.5 mm and 64 to 125 mm respectively.

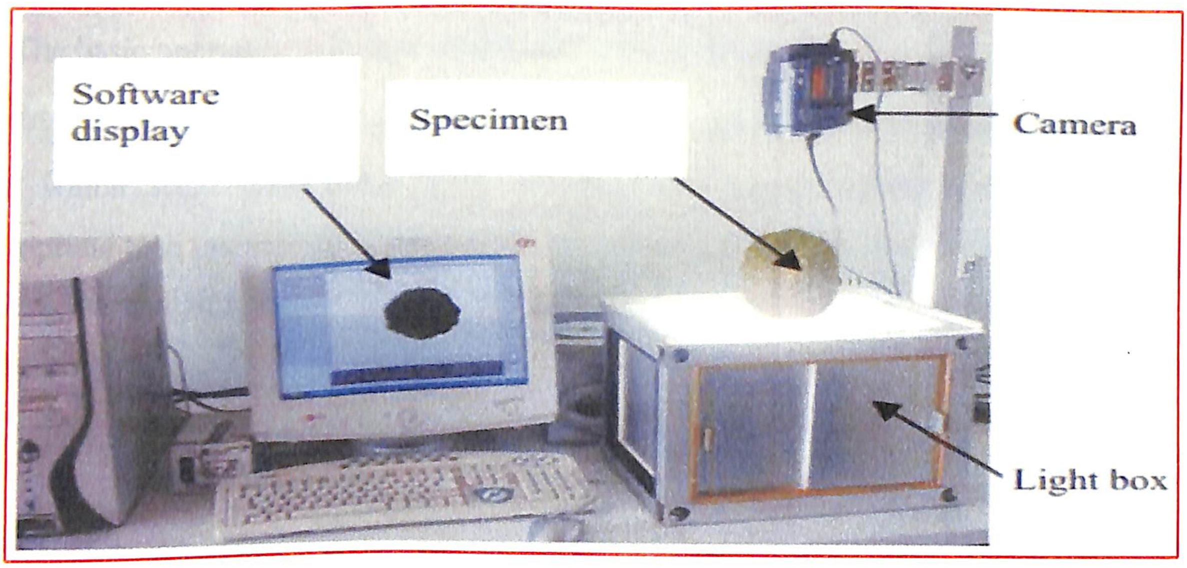

Fig. 2.2 Win Area UT-06 system

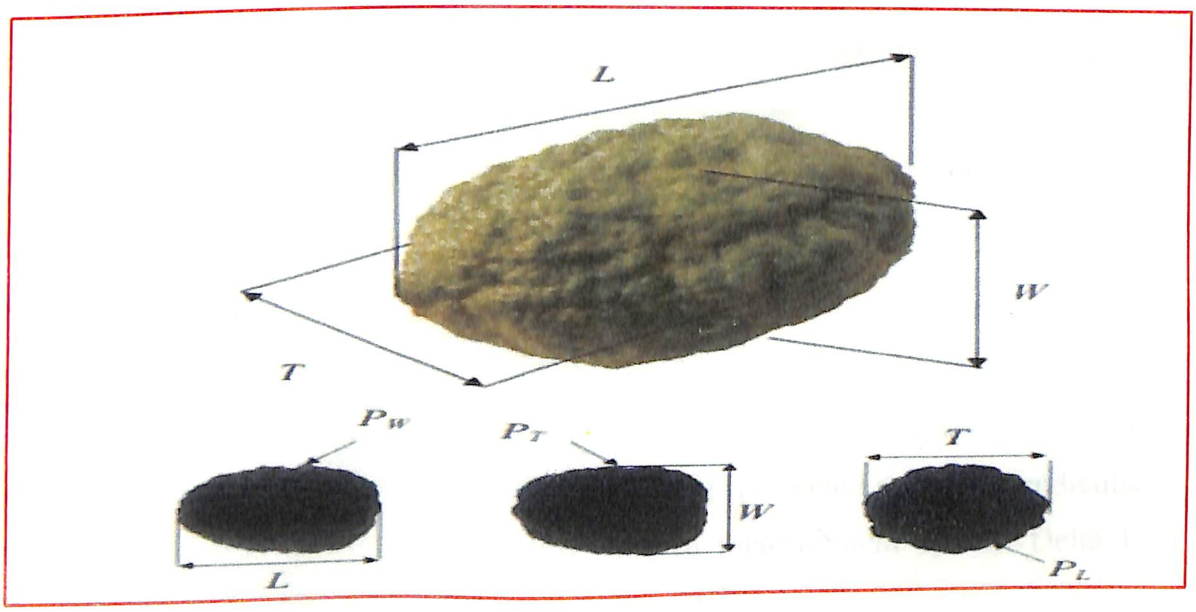

Fig. 2.3 Projected areas and dimensions of bergamot fruit

Sharifi *et al.* (2007) reported the length, width and thickness of the orange fruit which were recorded with an accuracy of 0.05 mm using a set of Win Area-UT-06. The basic operating principle of this set is image processing.

Jahromi *et al.* (2008) reported the selected engineering properties of the date fruit which were determined using a image processing technique to develop appropriate technologies for its processing. In order to obtain the fruit dimensions and projected areas, Win Area UT-06 system was used. This system consists of following 4 components:

a) Sony photograph camera, model CCD-TRV225E,

b) Device for preparing media to picture taking,

c) Capture card named Winfast, model DV2000,

d) Computer software programmed with visual basic 6.0.

In this system, fruits images were acquired by camera and the captured images of date fruits are transmitted to the computer card which works as an analogue to digital converter. The digitized images are then processed in image processing window by computer software to provide the three orthogonal images of fruit that determines fruit size and projected area.

Jannatizadeh *et al.* (2008) conducted the studies on physical properties of Iranian apricot (*Prunus armeniaca L.*) fruit by image processing to understand the behaviour of the product during the postharvest operations. The fruit linear dimensions *viz.*, length, width and thickness as well as projected areas perpendicular to these dimensions were determined using a area measurement system Delta-T, England. Total error for these objects was less than 2%.

Lino *et al.* (2008) conducted the studies on image processing techniques for lemons and tomatoes classification. The classification of tomatoes and lemons was done based on color and size, respectively using a Image J software.

Ullah and Haque (2008) conducted the studies on fruiting, bearing habit and fruit growth of jackfruit germplasm. The digital vernier callipers and measuring tape were used to measure the fruit dimensions *viz.*, length, diameter etc. In order to determine fruit dimensions, the equivalent distance of the apex to the base and longest dimensions perpendicular to the length are to be considered as fruit length and diameter respectively.

Shamsudin *et al.* (2009) conducted the experiments on physical properties of pineapple fruit. Digital vernier calipers were used for determining the fruit length and diameter for both with and without peel. The observed values for length and diameter of fruit with peel were varied from 119.26-136.51 mm and 93.85-106.93 mm, respectively whereas, values for the fruit without peel were found 103.49-124.59 mm and 82.93-98.17 mm respectively.

Chakespari *et al.* (2010) studied about mass modeling of two apple varieties by geometrical attributes. Digital calipers (0.01 mm accuracy) were used for determining the fruit size. In order to obtain average size, they considered three linear dimensions *viz.*, length (equivalent distance of the stem from top to the bottom calyx), width (longest dimension perpendicular to length) and thickness (longest dimension perpendicular to length and width). Whereas, projected area of each fruit which are perpendicular to length, width and thickness were recorded with an accuracy of 0.05 mm using a Win Area UT-06 system.

Mohan (2012) determined some physical properties of ash gourd and cucumber by image analysis method to develop a seed extractor. Experiments were carried out using a standard digital camera, camera stand, computer and the AutoCAD software. The photographs were taken by fixing the camera in stand and the captured images of each fruit were processed in the computer using AutoCAD software. The outlines of the fruits were drawn and the dimension *viz.*, diameter, length and placental diameter was measured by providing proper scale factor (Fig. 2.4). The length and diameter of ash gourd varied from 190-395 and 156-205 mm respectively whereas in cucumber, values were found to be 178-258 and 96-147 mm respectively.

Jagadeesh *et al.* (2007) studied the important physico-chemical characters of jackfruits to determine the degree of divergence present among the selections. The dimensions of the jackfruits among the clusters varied from 32.33-45.50 cm in length, 19.50-24.02 cm in diameter and 1.03-1.44 cm in rind thickness.

Haq (2011) investigated the variation in jackfruit characteristics. Wide variation was observed in fruits characteristics like fruit length values from 20.50 to 60.60 cm and diameter 16.40 to 29.5 cm with the majority of the selections.

Kalita *et al.* (2014) investigated the morphological characteristics of elite genotypes of jackfruit collected from the different districts of Assam. Significant variation was observed in respect of fruit length 23.87-51.27 cm, fruit diameter 14-36 cm, core length 11.67-40.00 cm and core diameter 3.00-16.33 cm among the genotypes.

Kotoky *et al.* (2014) carried out the survey in different districts of Assam to study the qualitative traits of some jackfruit genotypes based on jackfruit descriptor described by the International Plant Genetic Resource Institute (IPGRI). The study revealed that, there was wide range of variability exists with regards to many desirable quantitative characters *viz.*, fruit length (19.50-62.08 cm), fruit diameter (7.00-24.00 cm) and fruit rind thickness (0.30-2.00 cm) among the different jackfruit genotypes.

Shyamalamma *et al.* (2014) investigated the physical properties of elite jackfruit genotypes collected from the Bangalore rural and Tumkur district. Study revealed that wide variation was observed in fruits characteristics like fruit length of 20.50-43.00 cm, fruit diameter of 14.50-22.00 cm and rind thickness of 0.60-2.00 cm among the jackfruit genotypes.

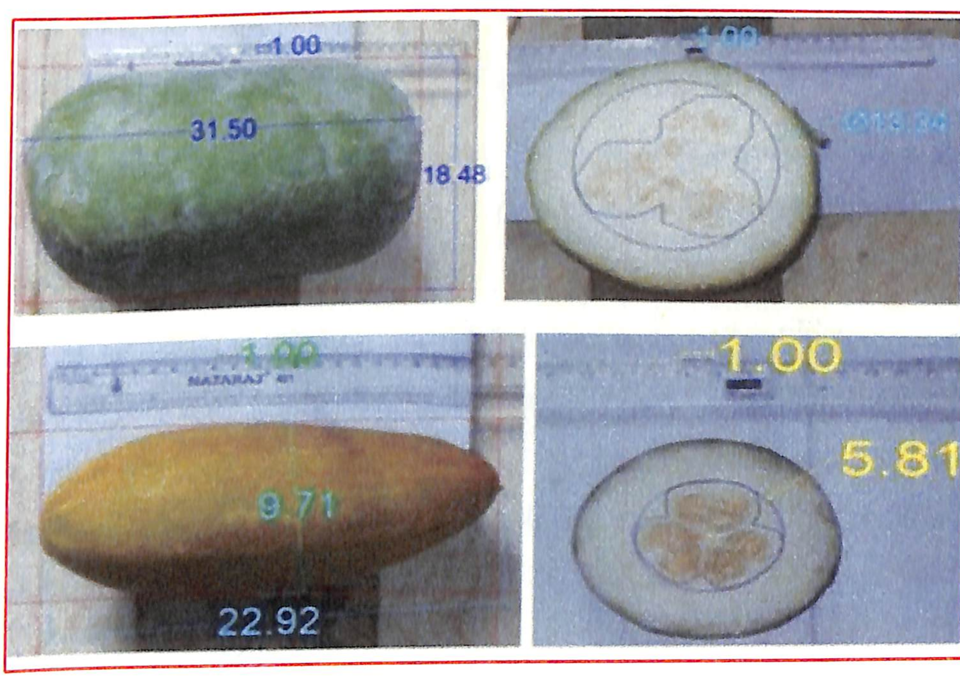

Fig. 2.4 Measurement of diameter, length and placental diameter of cucumber and ash gourd

Gomez *et al.* (2015) studied the physico-morphological characteristics of jackfruit accessions in Kerala. The dimensions of the jackfruits among the jackfruit accessions varied from 28.66-52.66 cm in length and 18.46-30.50 cm in diameter.

2.2.2 Mass

Azad (1989) investigated the physical properties of jackfruits harvested from late and early season. The mass of the whole fruit was recorded by electronic balance. Study revealed that, harvesting from the early season produced the fruits of biggest size (8.67 kg). The smallest jackfruit of 4.57 kg was observed in late season.

Mitra and Mani (2000) evaluated over 1,460 jackfruit trees in West Bengal. Wide variability was noticed in fruit weight which ranged from 1.22-17.30 kg among the genotypes evaluated.

Reddy *et al.* (2004) studied the physico-chemical characteristics of nine jackfruit clones from south Karnataka and found diversity in several characters. In these clones, maximum variability was noticed for the characters like fruit weight, weight of carpel and seed weight, which were ranged from 7.0-20.0 kg, 21.25-49.25 g per carpel (without seed) and 5.00-12.30 g, respectively.

Jagadeesh *et al.* (2007) studied the important physico-chemical characters of jackfruits to determine the degree of divergence present among the selections. Observed values of total fruit mass, seed mass, rind mass, flake mass and bulb mass of the jackfruits among the clusters varied from 4.68-14.86 kg, 0.71-3.67 kg, 2.06-4.85 kg, 1.61-5.62 kg and 3.11-9.28 kg, respectively.

Haq (2011) investigated the variation in jackfruit characteristics. Wide variation was observed in fruit weight ranging from 1.2-22.0 kg with the majority of the selections.

Kalita *et al.* (2014) investigated the morphological characteristics of elite genotypes of jackfruit collected from the different districts of Assam. Significant variation was observed in respect of fruit weight (2.16-10.66 kg), rind weight (1.01-6.26 kg) and weight of flakes per kg of fruit ranged from 0.34-0.76 kg among the genotypes.

Kotoky *et al.* (2014) carried out the survey in different districts of Assam to study the qualitative traits of some jackfruit genotypes based on jackfruit descriptor described by the International Plant Genetic Resource Institute (IPGRI). The observed values of fruit weight, fruit rind weight and weight of flakes per kg of fruit in the different jackfruit genotype were ranges from 0.58-15.45 kg, 0.02-1.23 kg and 0.06-0.37 kg, respectively among the different jackfruit genotypes

Shyamalamma *et al.* (2014) investigated the physical properties of elite jackfruit genotypes collected from the Bangalore rural and Tumkur district. Study revealed that wide variation was observed in fruits characteristics like fruit weight of 3.75-10.35 kg, fruit rind weight of 0.30-0.50 kg and weight of flakes per kg of fruit was 0.50-0.71 kg among the jackfruit genotypes.

Gomez *et al.* (2015) studied the physico-morphological characteristics of jackfruit accessions in Kerala. The observed value of fruit weight among the jackfruit accessions ranged from 3.95-20.13 kg.

2.3 Mechanical properties of jackfruit

2.3.1 Cutting force

The cutting strength is one of the most important tests in the mechanical properties. The test used to determine the materials strength and resistance of tissue to loading cutting force during cutting and coring operation. Some researches carried out work on requirement of cutting force to cut the fruits which helps in the particular equipment. The determination of cutting strength of different produce followed by various research workers were reviewed for the study.

Ohwovoriole *et al.* (1988) determine the cutting strength to identify the necessary cutting force of unpeeled and peeled cassava tuber. During this test, cutting tool (1.5 mm thick piece of sheet metal with sharpened edge at 30^0 angle) was placed between the plungers of the universal testing machine. The machine subjects the samples to compression at the speed of 20 mm/min and the resulting data were used to design a cassava peeler.

Visvanathan *et al.* (1996) studied the cutting strength of cassava tuber. The study revealed that, cutting force required to cut the cassava tuber depends on angle and velocity of the knife. The specific cutting energy for cassava tubers was observed to be a minimum (6.5 kJ/m^2) at a knife bevel angle of 30-45°, knife velocity of about 2.5 m/s and shear angle of 63-75°.

Emadi (2005) determined the mechanical properties of different varieties of pumpkin and melon fruit to develop a peeler machine. A cutting indentor, cutter device and holder for unpeeled and skin sample were designed and built for testing cutting force of a product in threes states *viz.*, unpeeled, flesh and skin. Sharpened edge (30° included angle) of stainless steel with 1.5 mm thick was used for designing and constructing the cutting indentor. Samples were prepared from the different parts of the pumpkin and melon using a cutting device and kept in the holder. The cutting indentor was fixed on the universal testing machine (UTM) which subjects a load at a speed of 20 mm/min. The study reveals that, the cutting strength of unpeeled sample of Jarrahdale, Butternut, Jap, Rockmelon, Honeydew and Watermelon was 5.15, 20.48, 10.99, 12.19, 9.55 and 10.13 N respectively whereas in skin samples, it was found as 2.82, 17.31, 9.41, 12.65, 9.96 and 10.16 N respectively.

Ambrish (2005) determine the maximum required force to cut the anola fruits, which ranged from 15.25 kg for the NA-7 varieties along the stem end side and the least requirement of cutting force was 7.43 kg for Kanchan variety along the axis of fruit.

Shamsudin *et al.* (2009) conducted the experiments on firmness of pineapple fruit at three different locations. The fruit firmness was measured using a cylindrical die of 6 mm in diameter with the Instron Universal Testing Machine (UTM). The result revealed that, force decreased with the stage of maturity from 74.79-42.93 N (top position), 62.56-37.20 N (middle position) and 57.14-36.04 N (bottom position) due to cause of ripening process and storage period.

2.4 Peeler and corer machines for different produces

Peeling and coring operations are the important preliminary stage of fruits and vegetables processing. The price and quality of the processed product is highly dependent on these stages. Manual peeling and coring is possible for all products but high losses and consumption of time and labour, have motivated the peeling industry to use mechanical peeler. There is a number of mechanical peelers and slicer/cutting machines are developed to suit the peeling and slicing of either a particular product or a group of products. In general, mechanical peelers are classified into various groups on the basis of type of mechanism that can incorporate during peeling system. The mechanical peelers include abrasive devices, devices with blades, rollers and drums. There is a variety of peeler and slicer machines which are developed by various research scientists to peeling and slicing/cutting of different types of fruits and vegetables *viz.;* pumpkin, apple, mango, pineapple, melon, papaya, cucumber etc.. However, no information is available on mechanical tool for peeling, coring and cutting of jackfruits. Also, there is no published literature article related to jackfruit peeler cum corer machine. A review of peeler and slicers machines for different produces is presented below.

Odigboh (1976) designed a mechanical cassava peeler. The machine comprises of two cylinders which are fixed inclined at an angle of 15° to the horizontal plane and parallel to each other with a clearance of 20 mm. Knives are fixed on the surface of the driver cylinder, which is rotates clockwise at 200 rpm. The driven cylinder which has a abrasive surface, also rotates clockwise at 88 rpm. When the cassava pieces are fed to the space between the cylinders products are being peeled off, while the cylinders rotate anticlockwise and move down.

Agrawal *et al.* (1983) developed a abrasive brush type ginger peeling machine. The main parts of the machine are two continuous abrasive vertical brush belts, which are driven in opposite directions with a downward relative velocity by a variable-speed electric motor. When the two belts are driven in opposite direction causes an abrasive action on ginger passing in between while the downward relative velocities provide the downward movement of the ginger.

Ewald (1986) developed an apple corer having four molded plastic components fitted together to form the design. It consists of hollow cutting tube, core remover which is slides along the cutting tube, handle attached at the end of the cutting tube and compression plug. The tip of the cutting tube has serrated teeth for easier boring into the apple. Finally, cutting tube was removed from the bored apple and the resulting core left in the tube is ejected by sliding the core remover towards the tip of the cutter.

Rose *et al.* (1987) patented an apparatus for removing the peel from pineapple. It consists of tubular knife which having toothed cutting edge to cut through a pineapple and elongated guide telescopically positioned within the tubular knife. The elongated guide adopted to direct the toothed cutting edge towards a pineapple that is interposed between the guide and a cutting pad. The mechanism for moving the tubular knife towards the cutting pad includes leveraged means, which reduces the force required to move tubular knife through the body of fruit. Flexible elongated guide increase the effective diameter of the guide and allows the apparatus to be used with different diameter tubular knives for different size pineapples. The core tube and the tubular knife were coupled together and move simultaneously.

Cohen and Siegel (1994) patented a fruit and vegetable peeler. The peeler included a head portion for engaging a fruit/vegetable, a handle for gripping the tool and flexible portion for permitting the head portion to pivot relative to the handle. The head portion of the tool carries the cutting blade, which is inwardly curved along its longitudinal length to provide a bow shaped construction. The flexible portion permits the cutting blade to follow the natural contour of fruits/vegetables, so that the cutting blade easily passes over the surface of the fruit/vegetable.

Sommer (1997) described a device for peeling elongated vegetables, preferably asparagus. The device includes a housing equipped with a passage designed to allow a stick of asparagus to be inserted. Inside of the housing fitted with several peeling blade, which are oriented in different directions of the passage and act on the stick of asparagus. At least one of the blades can move crosswise to the elongated direction of the passage and pushes flexibly towards the stick of asparagus.

Protte (1999) discussed a peeler machine for stalk-like vegetables, comprising a plurality of knife stations that are successively arranged along the vegetable moving inside the machine. The machine also includes a plurality of pairs of feed rollers and each pair is supported between successive knife stations in order to carry and push the stalk-like vegetables through the knife stations.

He and Tardif (2000) discussed a peeler machine equipped with blades to peel vegetables. The vegetable, which is fixed in the hollow base of the machine, can be rotated by screw shaft on the top. As the rod rotates manually by a hand, simultaneously product also started to rotates at same direction. A blade, which is connected to the supporting rod and pressed by a spring, moves against the vegetable to be peeled. When the vegetable start rotating, the peeling blade removes the peel.

Martin (2000) patented a peeling machine for peeling of various fruits and vegetables. The peeler machine equipped with a rotatable upper holding assembly and a lower holding assembly connected to a frame for securing and rotating the produces to be peeled (Fig. 2.5). The lower assembly was coupled with air cylinder in order to secure the fruits/vegetables between the upper and lower holding assemblies.

A movable carriage assembly (linear direction) is coupled to the frame and containing a cutting assembly which is engaged with the end of a second cylinder. As the carriage assembly moves upwards, the extension of the second air cylinder pushes the cutting assembly towards the fruits/vegetables, as a result peeling will take place.

Gingras (2001) described an apparatus for peeling of vegetables of round/oval shape *viz.*, cucumbers, turnips, carrots or potatoes. The machine has a frame including an adjustable hole to receive and let pass the vegetables to be peeled. The frame also equipped with several knives in such a manner that can slide towards the centre of the hole. The knives are distributed all around the frame in an equal manner and each carries a blade extended tangentially within the hole. Therefore adjacent part of the vegetable peels introduced into and pushed through the hole. Tension spring is provided between each blade and inner surface of the blade in order to push the knives towards the centre of the hole. This peeler allows peeling vegetables in a single pass or with a minimal number of passes.

Harding (2001) patented a peeler for convex surface of a fruits and vegetables. The machine includes a U-shaped peeling blade and a feeder which grips and contacts the fruits/vegetables at a position opposite the apex of the peeling blade. This apparatus also includes at least one guide for guiding the fruits or vegetables to pass in front of peeling blade.

Ridler (2001) presented a peeling apparatus for fruits and vegetables. The apparatus comprises of traversing blade which continuously and intermittently rotates in the opposite direction to a rotating fruits/vegetables. The apparatus was designed in such a way that it is controlled and powered manually. The operator rotates the fruits/vegetable that is placed on a detachable arbor by one hand and at the same time peeling blade was controlled by another hand.

Ukatu (2005) developed an industrial yam peeler. It consists of yam tuber container, conveyor system, tuber guides and peeling chamber. The yam tuber container holds the tubers ready to be peeled. The conveyor system consists of four pair of cylindrical roller for feeding unpeeled tubers to the machine and another two pairs for withdrawing peeled produce. The spring loaded tuber guides ensures the incoming tuber is directed to the peeler blade. The peeling chamber consists of three peeler arms which are spring loaded to provide the pressure needed for peeling and allow to accommodate the varying size of tubers. The peeler blade welded on the peeler arm scrapes the tuber at pre-set depth.

Kim (2006) patented a fruits peeler with cutting part. The simple device consists of a single piece of metal piece with a round peeling part inside of metal and cutting part outside of the same metal to peel and cut fruits. Peeling part removes the peel from round and convex surfaces of fruits and cutting part is used to cut the fruit to eatable size.

Emadi *et al.* (2008) developed a mechanical peeler for pumpkins, using an abrasive-cutter brush. Vegetable holder and peeler head are the two main parts of the machine (Fig. 2.6). The vegetable holder made up of disc for carrying the produce circularly on a horizontal plane and it supplied rotational velocities up to 300 rpm by an electric motor. The peeler head was designed to provide the perpendicular access to the produce's surface. A separate electric motor was used with higher speed limit (2000 rpm) to carry the abrasive-cutter brushes on its output shaft. To provide the flexibility during peeling, whole peeler head attachment was mounted on pivoted bracket. The cutting action causes the effective peeling.

Siti Mazlina *et al.* (2010) designed and developed an apparatus for grating and peeling fruits and vegetables. The machine consisted of grater, pushrod, trident, peeling blade, arm and end-cutting blade. This machine was fabricated from food grade stainless steel. The trident was fixed on the centre of machine body which supports the fruits and vegetables to be grated and peeled by providing circularly motion on a horizontal plane. The adjustable pushrod was placed opposite to the trident and on the same axis. The main function of the pushrod is to hold the fruit up

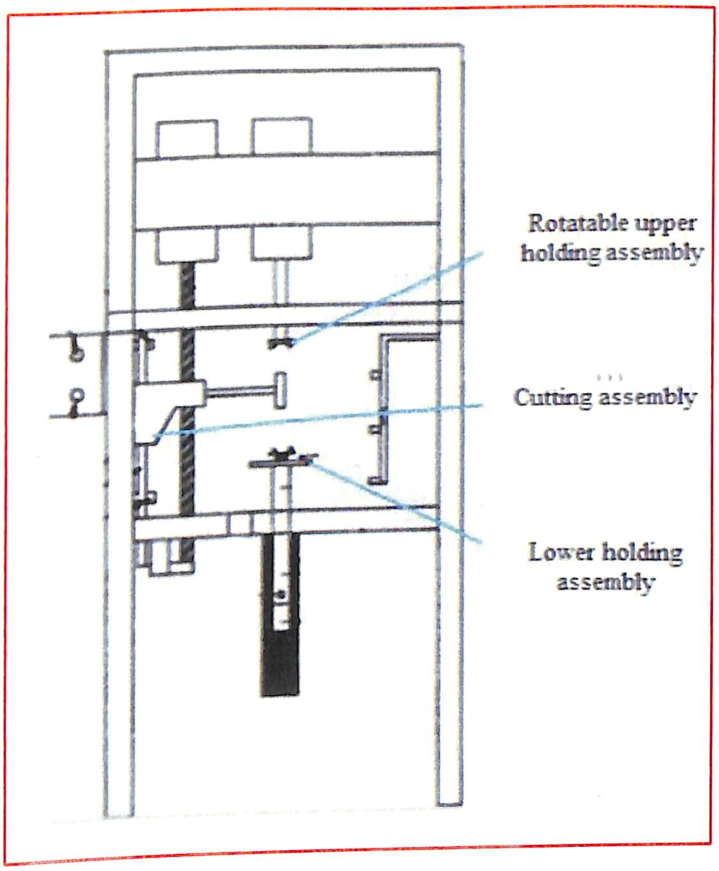

Fig. 2.5 Fruit peeler

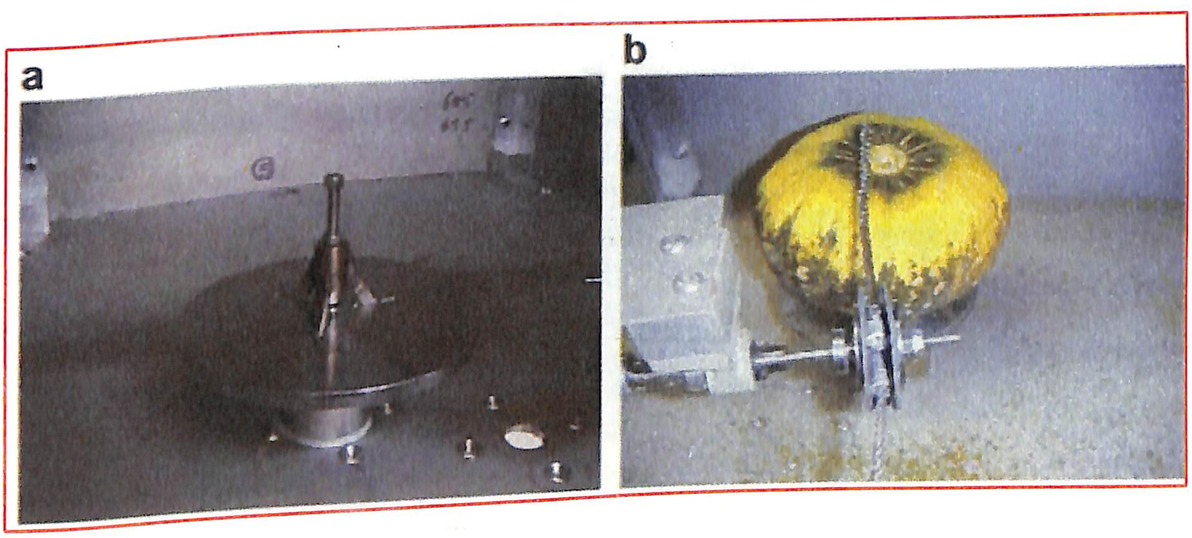

Fig. 2.6 (a) Vegetable holder (b) Peeler head

to enable the rotation and to push the fruit against the trident. The grater was situated on a handle which is movable to grate the fruit/vegetables for food decoration purpose. The arm was located on sliding vector which enable to move parallel to the fruit rotational axis and supports the peeling blade, which peels the fruits and vegetables. Elastic system was connected between arm and peeling blade. The function of the elastic system is to presses the arm softly on the fruit profile, holds the peeling blade position against the fruit profile and enables the peeling blade to move on fruit profile, so that machine automatically peels the fruits and vegetables that are spherical and oval shape (Fig. 2.7). Pair of end-cutting blades located on another handle to cut the fruit ends after the completion of peeling and grating operations. This machine is useful to grate the fruits and vegetables with or without scales on the skin. There were some fruits and vegetables *viz.*, cucumber, carrot and papaya that were grated using this operation (Fig. 2.8).

Ientile (2013) patented a geared melon peeler for peeling melon fruit from the melon rind. It consists of handle member, U-shaped base member and spring loaded cutting blade. The cutting blade was fixed between two arms of base member by means of rotating shaft to a series of toothed sprockets. The toothed sprocket was designed in such a way that could allow device to be rotated approximately 75° angle from first position to a second position to achieve the cutting depth into the melon. After the completion of the peeling, spring automatically returns the cutting blade to its original position.

Singh *et al.* (2013) designed a hand operated pineapple peeler-cum-slicer. Slicing plate and core remover shaft are the two main important parts of this design. Stainless steel pipe of 22 cm length and 2.5 cm diameter was used for constructing the core remover shaft. One end of the corer was kept with sharp teeth for easy penetration during the coring operation. For constructing slicing plate, the stainless steel plate of 7.0 cm diameter was attached to the pipe in helical manner around the corer with a gap of 1.5 cm between grooves for cutting the pineapple rings. It

Fig 2.7 Peeling products (a) papaya (b) papaya flesh (c) papaya skin

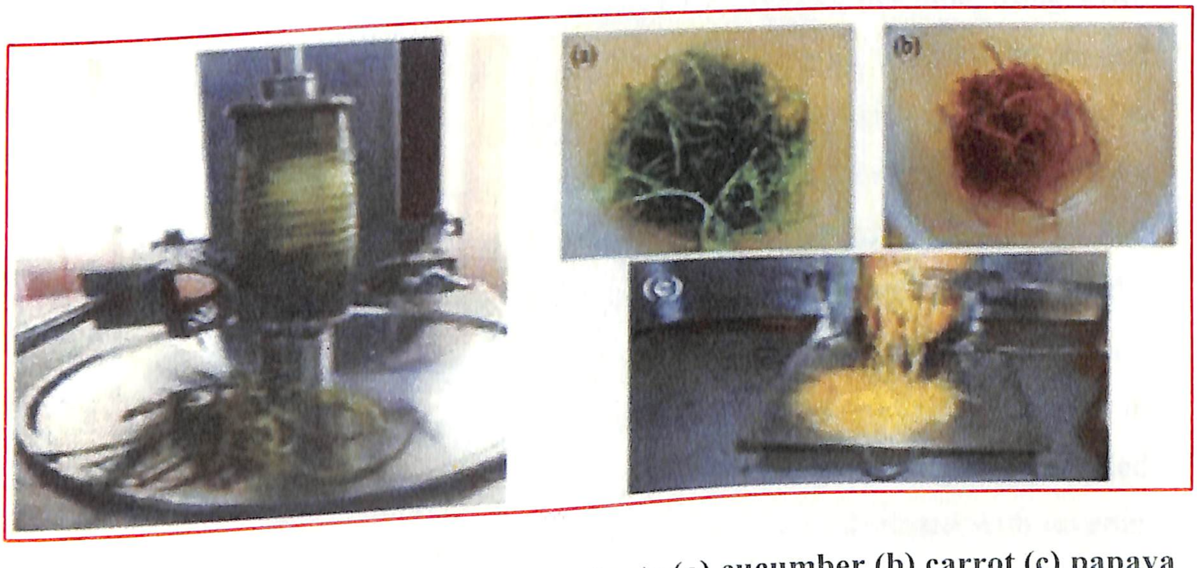

Fig 2.8 Grating cucumber; grating products (a) cucumber (b) carrot (c) papaya

simultaneously removes the core and produces pineapple rings of uniform thickness and diameter in a single motion. The designed device works satisfactorily with easy operation. efficient, time saving and economical for the farmers.

Anonymous (2015) developed a jackfruit peeling machine to remove the peel from whole jackfruit. The unit consists of a tubular knife, toothed cutting edge and elongated guide. The toothed cutting edge was designed in such a way that could cut through a body of jackfruit and fixed elongated guide telescopically positioned within the tubular knife to direct the toothed cutting edge towards the jackfruit. The mechanism for moving the tubular knife towards the cutting pad and through the body of a jackfruit includes leveraged means designed to reduce the force required to peel the jackfruit through tubular knife, which peels off the skin of jackfruit. The capacity of peeling machine was reported 6 pieces per minute which is fast and safe.

Thongsroy and Klajring (2015) designed a fruit peeling machine, using a two way blade. The main parts of the machine are peeling blade set, fruit holder set and controller set. The peeling blade set comprises of peeling blade with edge diameter of 2.7 cm and pneumatic cylinder which acts as controller of peeling blade set closely connected with fruit surface. The peeling blade set was designed in such a way that could be able to move linear direction (peeling up and down) by turning around the spiral screw shaft. Upper axle of the fruit holder set was connected with electric motor in order to spin fruit whereas, lower axle connected with pneumatic cylinder in order to grab fruit. Two electric motors with 1.0 hp are the power sources provided for fruit holder and peeling blade set. The controller set was fabricated with inverter to adjust the rotational speed of motor. The performance evaluation of designed peeling machine was carried out with Holland variety of papaya and Sun Lady variety of cantaloupe fruits (Fig. 2.9).

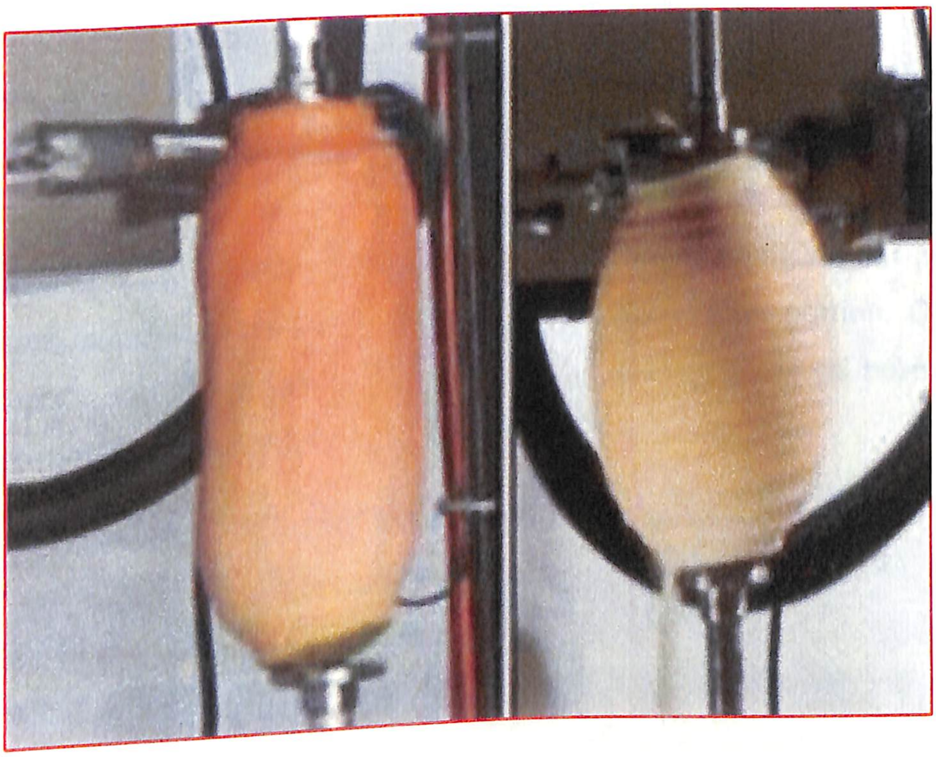

Fig 2.9 Papaya and Cantaloupe peeled

2.5 Cutting/slicing tool for different produces

Ganesan (1995) reported that tripod-like device was designed for coconut dehusking. The configuration of the blade was selected to suit various sizes of the coconut. The curvature and sharpness at the edge of the blade was found to be critical for smooth penetration of the blades into the husk. The force required for dehusking depends on the size and shape of the nut. The designed device enables easy separation of husk from the nut.

Thompson and Harrell (2003) invented a pumpkin cutting apparatus. It includes a tubular shaft, cutter tool and plunger shaft which extends through the tubular shaft and cutter tool. The cutter tool was designed in such a way that could cut a pumpkin and retaining the cut portion. When elongated plunger shaft pushed down the cutter, pumpkin was subjected to cut inside the cutter portion. Once a cutting is complete, the plunger shaft brings the cutter tool in its original position to eject the cut portion from the cutter.

Best and Kennedy (2005) described a food slicing apparatus. It consists of handle, roller and rigid blade; these are made of same/different materials. Roller and blade are rotatably mounted to the handle. Grip portion and yoke are the supporting members of handle and made of plastic and stainless steel materials respectively. One side of blade includes a cutting surface, which is a decline at an angle relative to a plane of the top surface of blade to cut the food and another side of blade was connected with rein forcing rib, which serves the reinforce blade. Therefore blade can easily slice foods of varying hardness.

Pattenden (2011) patented a tool to pierce and split a coconut to facilitate removal of the water and meat from the nut. It consists of body frame, produce required size to accommodate small to bigger dimensions of coconuts and constrictor cup, a shaft which has releasably engaged tap and splitter assembly. The body has a hub aperture to receive the shaft, which push both the cutting and splitting tool through the body of coconut.

2.6 Performance evaluation of peeler and slicer machines

Agrawal (1987) evaluated the performance of a ginger peeler machine. The peeling efficiency and the ginger meat loss were determined by the following formula

$$\text{Peeling efficiency} = \frac{(\text{Weight of total skin removed by machine})}{(\text{Weight of total skin on ginger})} \times 100 \quad \ldots 2.1$$

$$\text{Meat loss} = \frac{(\text{Weight of ginger meat loss during mechanical peeling})}{(\text{Total weight of the sample})} \times 100 \quad \ldots 2.2$$

The peeling efficiency and meat loss of the machine at full capacity (20 kg/h) were found as 71% and 1.6%, respectively.

Singh and Shukla (1995) reported the peeling efficiency and peel losses of developed potato peeler which were calculated by using the formula

$$\text{Peeling efficiency} = \frac{\begin{bmatrix}\text{Fraction of peel} \\ \text{on raw potato}\end{bmatrix} - \begin{bmatrix}\text{Fraction of remaining} \\ \text{peel on peeled potato}\end{bmatrix}}{[\text{Fraction of peel on raw potato}]} \times 100 \quad \ldots 2.3$$

$$\text{Peeling losses} = \frac{[\text{Weight of raw potatoes}] - [\text{Weight of peeled potatoes}]}{[\text{Weight of raw potatoes}]} \times 100 \quad \ldots 2.4$$

Ukatu (2005) calculated the peeling efficiency and peel losses of yam peeler as follows

$$\text{Peeling efficiency} = \frac{\begin{bmatrix}\text{Surface area of} \\ \text{unpeeled tuber}\end{bmatrix} - \begin{bmatrix}\text{Total surface area of} \\ \text{unpeeled patches}\end{bmatrix}}{[\text{Surface area of unpeeled tuber}]} \times 100 \quad \ldots 2.5$$

$$\text{Peeling loss} = \frac{\begin{bmatrix}\text{Mass of tuber}\\ \text{before peeling}\end{bmatrix} - \begin{bmatrix}\text{Mass of tuber}\\ \text{after peeling}\end{bmatrix}}{(\text{Mass of tuber before peeling})} \times 100 \qquad \ldots 2.6$$

The peeling efficiency and peel loss (the lost tuber flesh) of the yam peeler were found 60-80% and 11.22-17.30% respectively.

Jain *et al.* (2007) evaluated the abrasive peeler cum polisher for ginger. Peeling efficiency and peel losses of peeler were calculated as follows

$$\eta = \frac{(Y - X)}{(Y)} \times 100 \qquad \ldots 2.7$$

$$M = \frac{w - (Y - X)}{(W)} \times 100 \qquad \ldots 2.8$$

Where η = peeling efficiency (%), Y = weight of total skin on ginger (g), X = weight of skin removed by hand trimming after mechanical peeling (g), M = meat loss (%), w = total reduction in weight during mechanical peeling (g), W = total weight of the sample (g).

The average peeling efficiency of the machine was found as 74, 81.2 and 81.7% at operation time of 8, 10 and 12 minute with a meat loss of 1.54, 2.58 and 3.82% respectively. The data reveals that peeling efficiency and meat loss increased with the increasing holding time for ginger in the peeler drum.

Emadi *et al.* (2008) evaluated the mechanical peeler for pumpkins using an abrasive-cutter brush. Peel losses and peeling effects were calculated by formula

$$y_1 = \frac{(W_1 - W_2)}{(W_1 \times t)} \times 100 \qquad \ldots 2.9$$

$$y_2 = \frac{(A_1 - A_2)}{(A_1 \times t)} \times 100 \qquad \ldots 2.10$$

Where y_1 = peel loss, percentage of initial produce weight removed during peeling/min. W_1= weight of unpeeled produce (g), W_2 = weight of peeled produce (g), y_2 = peeling effect, percentage peel that is removed from the initial skin/min, A_1 = fraction of peel inside the internal area of ring indicator before peeling (assumed to be 100), A_2 = fraction of peel inside the internal area of ring indicator after peeling.

The peeler was found to operate with peeling effects of 18.60% per min for concave areas and 20% per min for convex areas at 0.1% per min peel losses.

Jimoh and Olukunle (2012) evaluated the performance of an automated cassava peeling system for the enhancement of food security in Nigeria. Peeling efficiency and mechanical damage were determined using formula

$$\eta = \frac{(Mpc)}{(Mpr + Mpo)} \times 100 \qquad \text{...2.11}$$

$$\lambda = \frac{(Mf)}{(Mc + Mf)} \times 100 \qquad \text{... 2.12}$$

Where η = peeling efficiency, λ = mechanical damage, Mpo = weight of peel collected through the peel outlet of the machine (kg), Mpr = weight of peel removed by hand after machine peeling (kg), Mpc = weight of collected peel (kg), Mf = weight of tuber portion which was removed along with the peel by the machine (kg), Mc = weight of completely peeled tuber (kg).

Result revealed that throughput capacity, peeling efficiency and mechanical damage of peeler ranged from 76-442 kg/h, 50-75% and 12-44%, respectively.

Singh *et al.* (2013) evaluated the performance evaluation of pineapple peeler-cum-slicer. The machine was found to operate with higher capacity of 20 fruits/h and peeling efficiency of 97.2% with less flesh wastage of 5.3%.

2.7 Material selection

Minimizing the chance of food contamination by designing a piece of equipment for ease of cleaning should be the goal of all processing equipment design engineers. If the proper grade of stainless steel is used in food processing, corrosion will not be encountered.

Coady *et al.* (2000) investigated the good manufacturing and material selection in the design and fabrication of food processing equipment. The two most common grades of stainless steel used in processing equipment are 1) Type 304: most common and versatile stainless steel with excellent forming and outstanding welding characteristics. It is readily brake/roll formed into a variety of parts for equipment and post weld annealing is not required to restore the excellent performance of this grade. 2) Type 316: better resistance to corrosion and more expensive compared to type 304. Stainless steels are also identified by their surface finishes. Common surface finishes found in food processing equipment are 1) #2B: which is smooth and dull finish. 2) #4, which is general purpose polished finish. Both the finishes are considered smooth. Smoothness is important because crevices provide places for bacterial growth.

Jullien *et al.* (2002) research work was carried to identify the surface characteristics relevant to the hygienic status of stainless steel for the food industry. It was investigated by number of residual adhering Bacillus cereus spores after a complete run of soiling and cleaning in place procedure. The 14 materials tested (304, 316 and 430 grades; pickling (2B), bright annealed (2R) and electropolished finishes) were shown to be highly hygienic with slight differences in adhering spores. However, tested materials were grouped into different classes according to their hygienic status.

Jellesen *et al.* (2006) reported the literature on metal release in the food industry. Stainless steel was the most widely used metallic material in the food industry. Examples of food products with a corrosive effect and cases concerning processes, storing equipment as well as cleaning and sanitising procedures were reviewed.

Agrawal *et al.* (2014) reported that AISI 304 stainless steel (SS) was used in applications like automotive, oil, gas and the food industry due to its excellent combination of corrosion resistance and mechanical properties.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter describes the conceptual design and fabrication of a machine for peeling, coring and cutting of jackfruit. Selected engineering properties related to the fabrication of tool and evaluation were also undertaken and appended.

3.1 Procurement of jackfruit

Matured, unripe jackfruits (*Artocarpus heterophyllus L, Moraceae* family) of Varikka variety were harvested from the instructional farm of K.C.A.E.T, Tavanur were used for the study. Fruit which bear only oblong/round shape were harvested from the selected trees.

3.2 Measurement of engineering properties of jackfruit

3.2.1 Physical properties of jackfruit

The major physical properties required for the development of the machine are fruit length, fruit diameter, core length, core diameter, rind thickness and fruit mass. Immediately after the harvest fifteen jackfruits were selected at random for the measurement of these physical parameters.

3.2.1.1 Fruit Length

The equivalent distance of the stem (top) to the calyx (bottom) was considered as fruit length and it was measured by image processing technique (Jahromi *et al.*, 2008). The image processing was carried out using a standard digital camera (Nikon: Coolpix P500), camera stand, computer and the ImageJ (version 1.51d) software. The jackfruit images were acquired by fixing the camera in a stand (Plate 3.1) with natural lighting. In order to get the images, jackfruit was placed on a white background to provide better contrast between the foreground (jackfruit) and background and scale was placed near the fruit to calibrate the pixel length during the image analysis (Plate 3.2a).

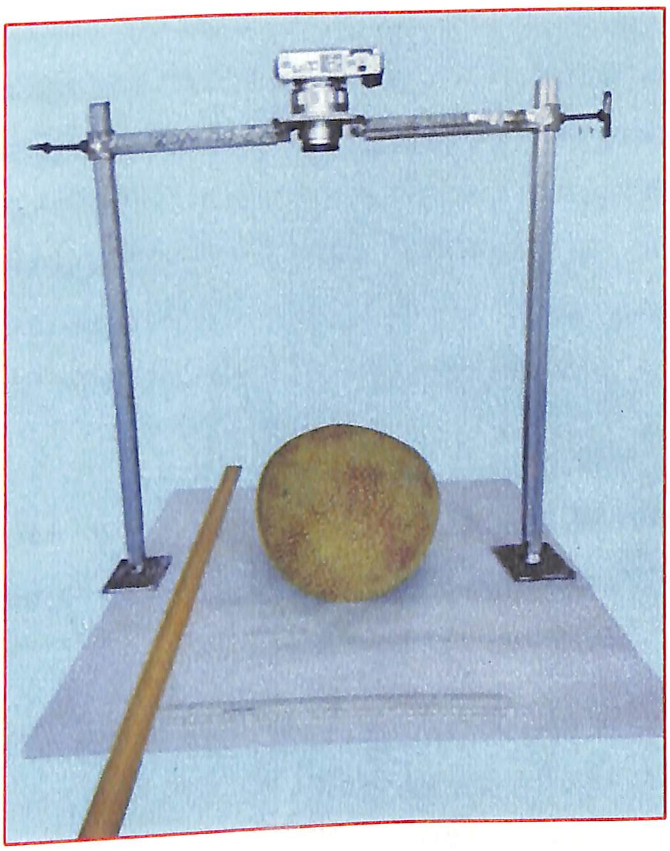

Plate 3.1 Digital camera on stand for image acquisition of jackfruit

The images acquired are preprocessed using standard commands in ImageJ. Initially the RGB image acquired is calibrated for its pixel length by using set scale command. A known distance of 1 cm was measured from the image and the number of pixels contained within 1 cm was scaled. The RGB image was converted into a grayscale image (Plate 3.2b). To remove the variations on the surface of the jackfruit, an averaging filter was applied to the grayscale image. The filtered image is shown in Plate 3.2c. Grayscale image has to be converted into a binary image for measuring the dimension (Plate 3.2d). In order to convert it into a binary image, thresholding was applied. ImageJ provides twelve thresholding techniques, out of which default thresholding was able to segment the jackfruit clearly. ImageJ provides an option called "Analyze Particle" which measure fruit length and diameter.

3.2.1.2 Fruit diameter

Longest dimension perpendicular to fruit length is to be considered as fruit diameter and it was measured by image processing technique as discussed in section 3.2.1.1.

3.2.1.3 Fruit core length

Distance from top (stem) to bottom of the core was considered core length and it was measured by image analysis method using AutoCAD software (version: 2017). The jackfruit was cut (length-wise) into two pieces from stalk to bottom. The cut jackfruit images were acquired by fixing the camera in a stand with natural lighting. In order to get the images, jackfruit was placed on a white background to provide better contrast between the foreground (jackfruit) and background and scale was placed near the fruit to calibrate core dimension during the image analysis. The captured images were processed with AutoCAD software to measure the core dimensions using standard commands. Initially, the outlines of the core portion were drawn. The core dimensions were measured with the help of scale which was provided during image capturing. Then, the maximum length of jackfruit core was determined as shown in Plate 3.3.

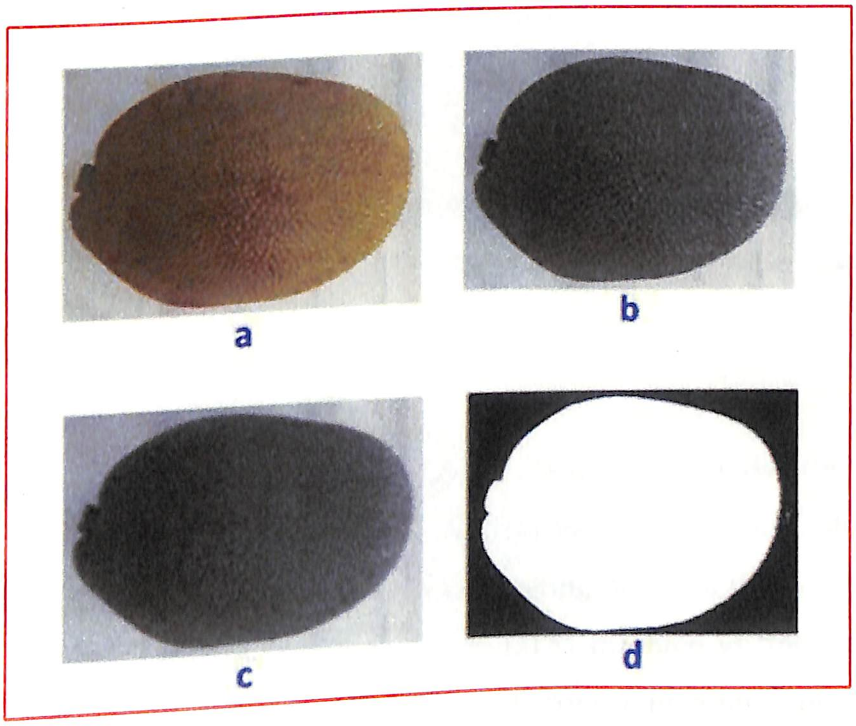

Plate 3.2 Image preprocessing for whole jackfruit (a) RGB image; (b) Grayscale image; (c) Image after applying average filter; (d) Binary image obtained after thresholding operation

3.2.1.4 Fruit core diameter

Longest dimension perpendicular to length of core is to be considered as core diameter and it was determined using the image analysis technique as discussed in section 3.2.1.3.

3.2.1.5 Fruit rind thickness

The rind was removed manually from the jackfruit using a sharp knife. Its thickness was measured in centimeter using a digital caliper with accuracy of 0.01 mm and the mean values were calculated.

3.2.1.6 Fruit mass

Mass of individual fruit was determined with an electronic balance of 0.1 g sensitivity and the mean values were calculated. The values were recorded in kilogram.

3.2.2 Cutting strength of jackfruit

Study of cutting strength is essential to design and fabrication of core removing tool and fruit holder for machine development. The cutting strength of peeled jackfruit was determined using a universal testing machine (UTM) TUE-CN-600 (Plate 3.4). Cutting probe (Fig. 3.1) used on UTM machine to find out cutting strength was fabricated with same dimension of core removing tool which is explained in 3.4.3.1. Five jackfruits were selected at random to measure the cutting strength. The machine consists of hydraulic cylinder motor with chain and sprocket drive, load indicator system, fixed cross rail and movable cross rail. The peeled jackfruit was placed on movable cross rail and the rail was raised until it touches the cutting tool. The machine subjects the samples to compression at the speed of 20 mm/min. The machine was operated until sharpen edge of the probe, cut the sample to a depth up to 30 cm (average core length of jackfruit). The load indicator system records the amount of load (kN) applied during the test. Same procedure repeated for

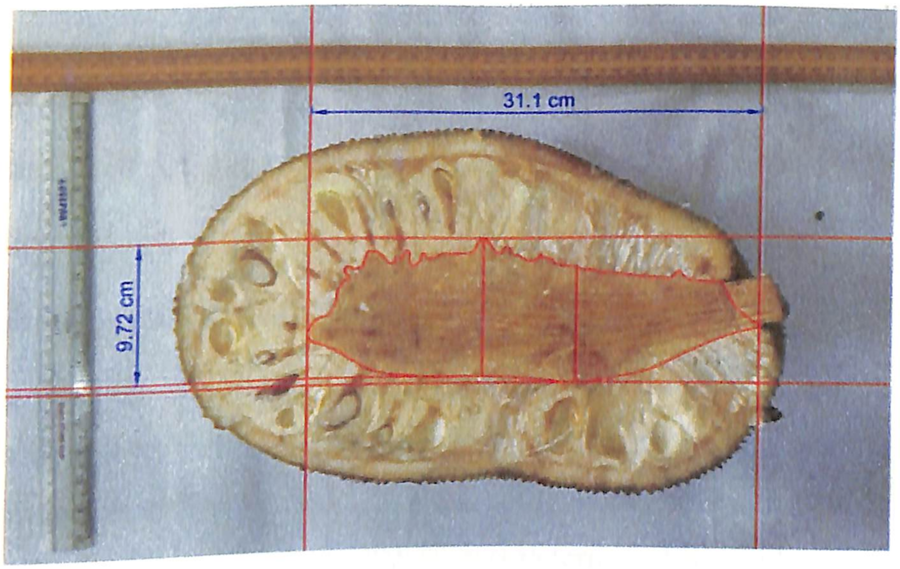

Plate 3.3 Measurement of length and diameter of jackfruit core

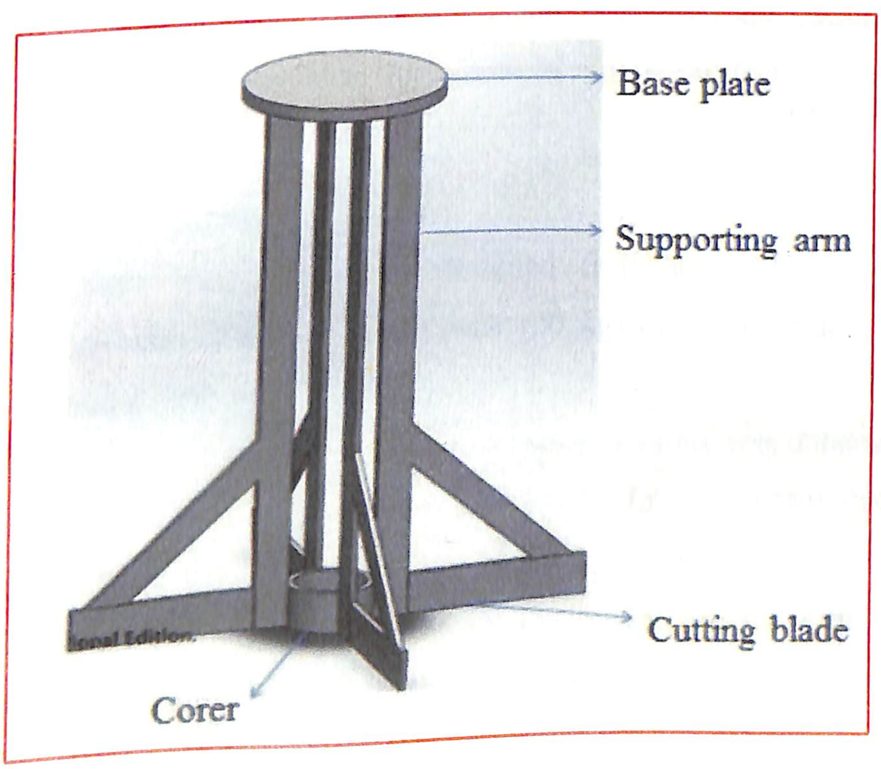

Fig. 3.1 Cutting probe

remaining samples and mean values were calculated. The determined cutting strength was used for simulation of core removing tool and fruit holder of a machine.

3.3 Simulation of machine tool

3.3.1 Simulation of core removing tool

Cutting strength of jackfruit was determined by cutting probe, but the factor of safety distribution of core removing tool at maximum loading and maximum operating condition was determined by using solid works software (2016) by the feature of design simulation. Factor of safety was determined by applying maximum cutting strength on 3D diagram of core removing tool. The minimum of 24 and maximum of 1.00 e+016 factor of safety (FOS) distribution were obtained for designed core removing tool (Fig. 3.2). This tool was not only used for coring and cutting of jackfruit and also acted as a rotatable upper holding assembly during peeling operation. Hence torsional forces may occur on the tool and cause bending and twisting of tool. So to overcome this problem minimum factor of safety is considered as 24.

3.3.2 Simulation of fruit holder

Maximum force was applied on designed fruit holder by considering maximum cutting strength (3500 N) and weight (20 kg) of jackfruit and also the weight of core removing tool.

From the Fig. 3.3 it is clear that, minimum factor of safety was obtained <1 in case of a newly designed fruit holder of 5.0 mm disc thickness. So that chances of bending may occur. When the fruit holder disc thickness was increased to 10.0 mm, the minimum factor of safety distribution obtained was 2.3 (Fig. 3.4). The fruit holder should stand without failure in case of maximum loading in operating conditions. For this, while designing fruit holder tool, the maximum expected force with FOS of 2.3 was selected as the design strength with 1cm thickness of disc.

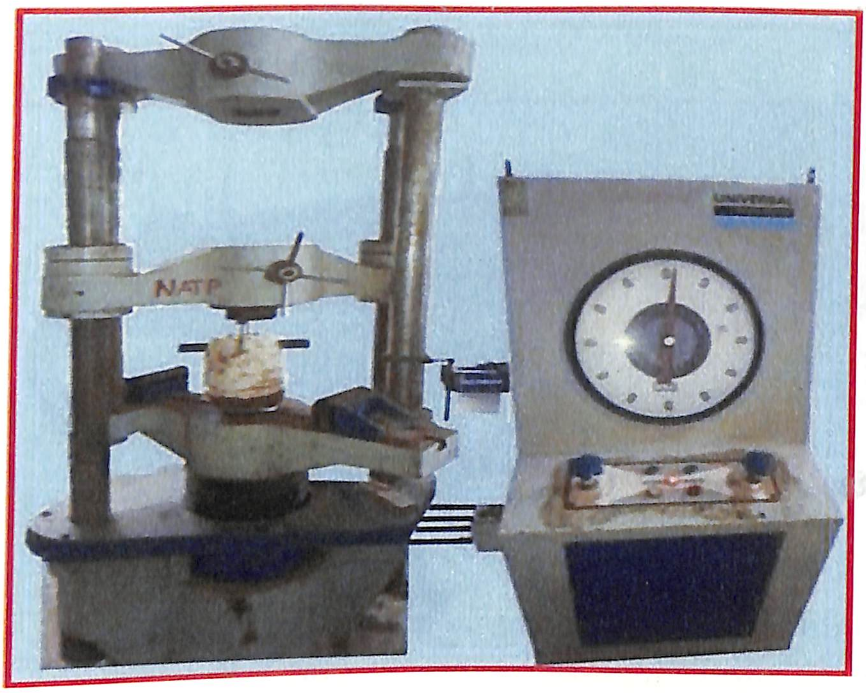

Plate 3.4 Universal testing machine (UTM)

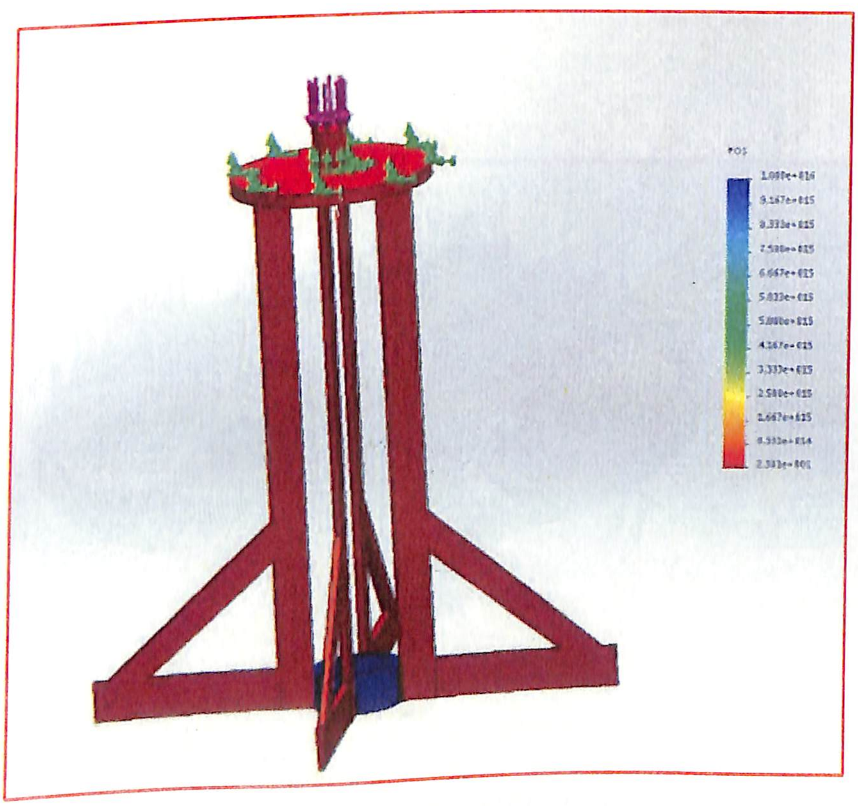

Fig. 3.2 Factor of safety of core removing tool

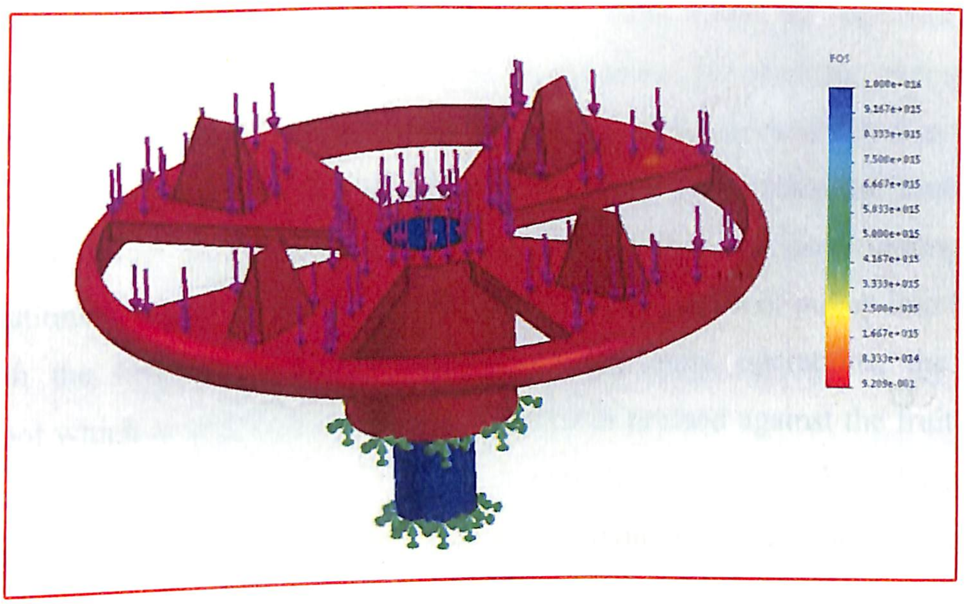

Fig. 3.3 Factor of safety of fruit holder (0.5 cm disc thickness)

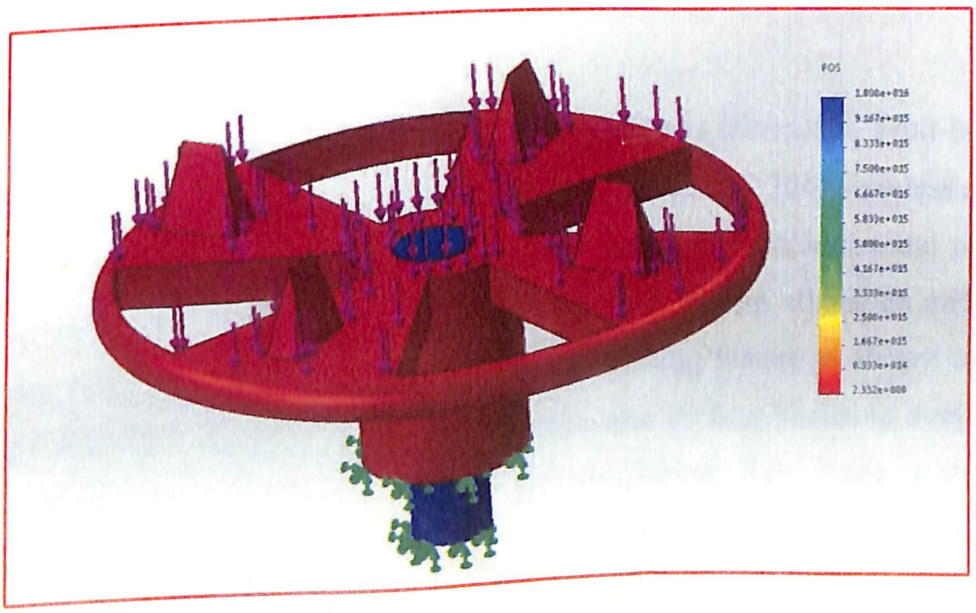

Fig. 3.4 Factor of safety of fruit holder (1 cm disc thickness)

3.4 Development of peeler cum corer for jackfruit

Based on the preliminary studies, peeler cum corer for jackfruit was developed and the performance was evaluated for the same. The working principle of peeling operation is, as the jackfruit rotates the peeling was done helically due to the linear motion of the blade from bottom to top. The clearance between the blade and peeler arm was fixed on the basis of thickness of the rind. Similarly cutting and coring operations was performed by converting the rotary motion of pulley into linear motion with the help of screw mechanism. During these operations, the core removing tool which is attached to the screw shaft was pressed against the fruit. The thickness of corer and cutting blades of core removing tool was fixed based on cutting strength of jackfruit. The major fabricated components of the machine are

1) Fruit holder
2) Peeler assembly
3) Corer assembly along with cutting mechanism
4) Power transmission unit
5) Frame assembly

3.4.1 Fruit holder

As per the result of design simulation, fruit holder is fabricated. Fruit holder consists of disc and blade, which are made up of food grade (SS 304) stainless steel. It was designed as a rotating disc that can carry the jackfruit on a horizontal plane. The dimensions of the disc were 1 cm thickness and 16 cm diameter and the trapezoidal sections cut out were made between the holding blades as shown in the Fig. 3.5 and Plate 3.5. The jackfruit was fixed on the disc by four blades to avoid the slippage between fruit and circular disc; each projection was made with the dimensions (2 cm height, 2 cm width and 0.5 cm thickness) and welded circularly at 4 cm radius of disc with equal distance. The shaft was made using MS rod and it consisting of two pulleys (diameters of 15.24 and 17.78 cm) in order to connect with motor and peeler assembly for power transmission. The adjustment of angular velocity of the jackfruit holder was carried out by changing the pulley on holder shaft with the help of optical tachometer.

3.4.2 Peeler assembly

Peeler assembly consists of screw shaft, peeler arm, blade and spring as shown in the Fig. 3.6 and Plate 3.6.

3.4.2.1 Screw shaft

The screw shaft was made using MS rod with square threads on the outer surface. The dimensions of the screw shaft were 67 cm length, 2.4 cm diameter and 2.3, 1.5 and 1.5 mm screw pitch, thread width and thread height, respectively. It was passed through the internally threaded circular passage of rectangular housing, which in turn attached to the peeler arm. The 12.7 cm diameter pulley made up of cast iron was fixed on the bottom of the screw shaft to take the drive from fruit holder shaft. The main function of the screw shaft is to provide a linear motion to the peeler arm by rotating on its own axis.

3.4.2.2 Peeler arm

The peeler arm was made using food grade SS 304 stainless steel having 17.5 cm length, 3 cm width and 0.5 cm thickness. One end of the peeler arm was connected to a rectangular housing, which in turn is attached to an internally threaded circular passage. For effective peeling another end of peeler arm was bent slightly at 35 angle which supports the peeling blade. The peeler was connected with screw shaft which enables the peeling blade to move parallel over the jackfruit profile, so that fruit was completely peeled from bottom to top.

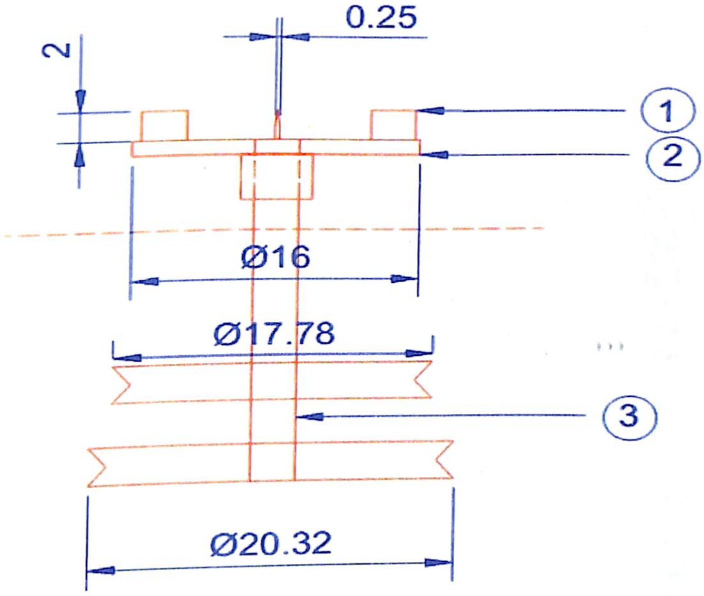

Fig. 3.5 Front view of fruit holder

All dimensions are in cm

1. Blade, 2. Disc, 3. Shaft

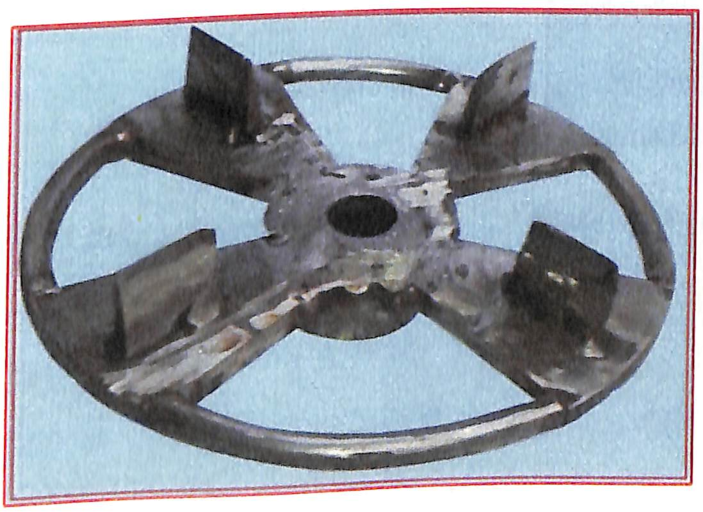

Plate 3.5 Fruit holder

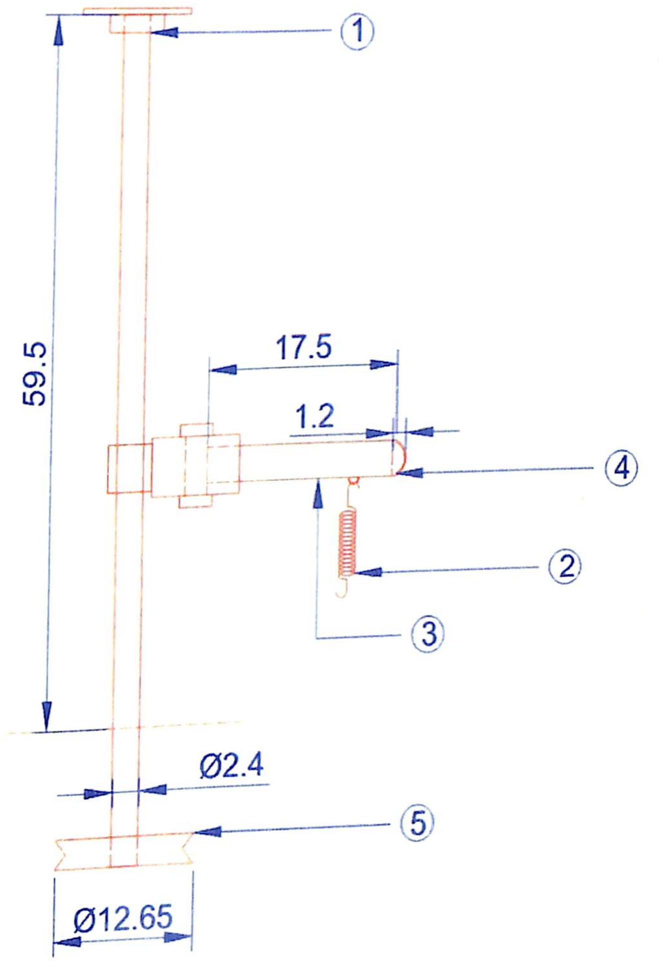

Fig. 3.6 Front view of peeler assembly

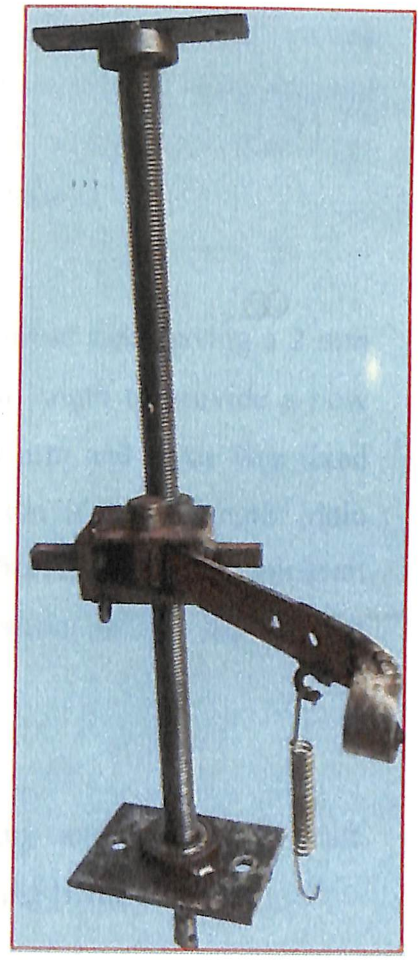

Plate 3.6 Peeler assembly

All dimensions are in cm

1. Screw shaft, 2. Spring, 3. Peeler arm, 4. Blade, 5. Pulley

3.4.2.3 Spring

The spring was attached between peeler arm and rectangular housing. The specifications of the spring were 8 cm length and 1.5 cm diameter. It provides flexibility to the peeling operation, so that cutting blade easily passes over the surface of jackfruit. A main function of the spring is to press the peeler arm softly over the fruit profile and holds the peeling blade in position against the jackfruit. Apart from this, spring aids the blade against the irregular surface of jackfruit.

3.4.2.4 Peeling blade

The blade was made using food grade SS 304 stainless steel having a 2 mm thickness which is inwardly curved along its longitudinal length to provide a bow shaped construction. Clearance of 1.2 cm between peeler arm and blade was fixed based on the rind thickness of jackfruit by neglecting 0.5 cm of spikes length. Main functions of the blade is to peel the rind out of whole jackfruit and able to traverse an angular displacement of 40° angle during peeling operation, which depends on diameter of the jackfruit.

3.4.3 Corer assembly along with cutting mechanism

Corer assembly mainly consists of core removing tool and screw shaft mechanism and it was situated on the middle of the supporting frame assembly.

3.4.3.1 Core removing tool

It consists of fruit corer, cutting blades, supporting arms and base plate; which are made using food grade SS 304 stainless steel. The fruit core removing tool comprising a circular portion with 5.5 cm internal diameter, 2.5 cm height, 4mm thickness to which the bottom edges were sharpened at 30° angle. The diameter of corer was chosen based on the average core diameter of the jackfruit. Four number of steel flat, each having a 20 cm length, 2.5 cm width, 4 mm thickness to which the bottom edges are sharpened which results in 10° included angle were used for fabrication of the cutting blades. The cutting blades are welded to the side portion of supporting arms as shown in the Fig. 3.7 and Plate 3.7. The length of cutting blades was chosen based on the average diameter of the jackfruits. The four supporting arms act as a supporting medium to cut the large size of jackfruit and which are welded between blade and corer with equal spacing between them. The bottom side of the each arms was ending with a sharp edge for 2 cm length whereas, top side was welded to a base plate having a diameter of 15 cm. The base plate was used to carry the load given for cutting and coring of large size of jackfruit without failure and its top surface was welded to a steel pipe having a 2.5 cm OD, 1.5 cm ID and 3.5 cm in length. This steel pipe was connected to the screw head with the help of bearings; therefore core removing tool was able to rotate in clockwise or anticlockwise direction as per our requirement.

Main function of the core removing tool is to perform fruit cutting and core removal as a single operation. When the core remover tool moved down, jackfruit was subjected to cut with sharpened edge of the tool until it reaches calyx of jackfruit. Once the tool moved upside the core removed from the fruit has to be pushed down by hand. Speed of cutting, coring operation depends on rpm of the corer pulley which was fixed based on the trials conducted to optimize the speed by changing belt and pulley.

3.4.3.2 Screw shaft mechanism

The screw shaft mechanism was made using MS shaft with square threads on the outer surface and cast iron pulley with threads on inside of the hole as shown in (Fig. 3.8 and Plate 3.8). The screw shaft with dimension of 3.8 cm diameter, 79 cm length, 0.58 cm screw pitch, 0.2 cm thread width and 0.18 cm thread depth was used. The main function of the screw mechanism is to convert rotary motion of pulley into linear motion of screw shaft which is connected to a core removing tool with the help of bearings. Two sliding arms were welded on screw head with equal distance between them, which acts as stopper for core removing tool when reaches the fruit holder disc.

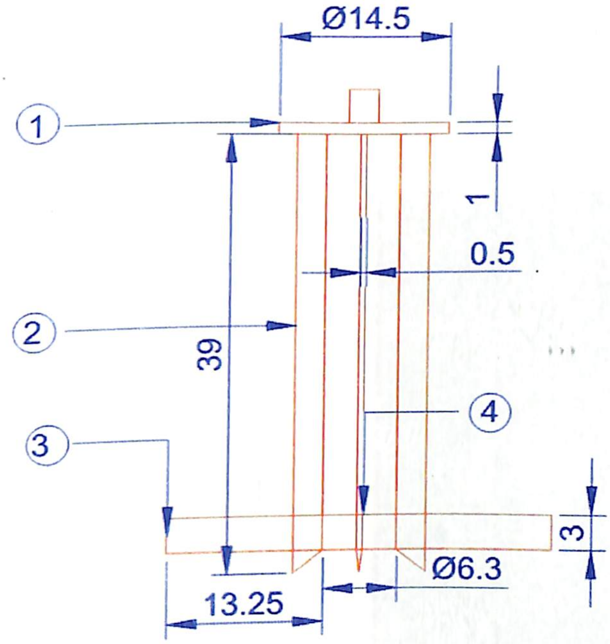

Fig. 3.7 Front view of core removing tool

All dimensions are in cm

1. Base plate, 2. Supporting arm, 3. Cutting blade, 4. Corer

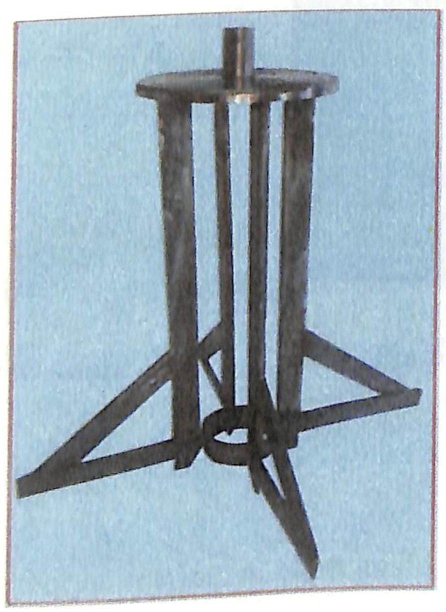

Plate 3.7 Fruit core removing tool

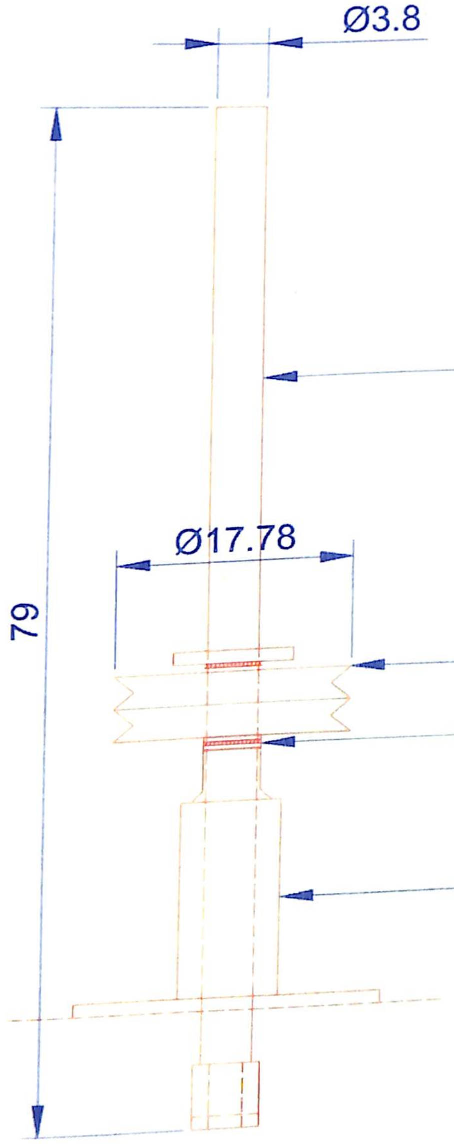

Fig. 3.8 Front view of screw shaft assembly

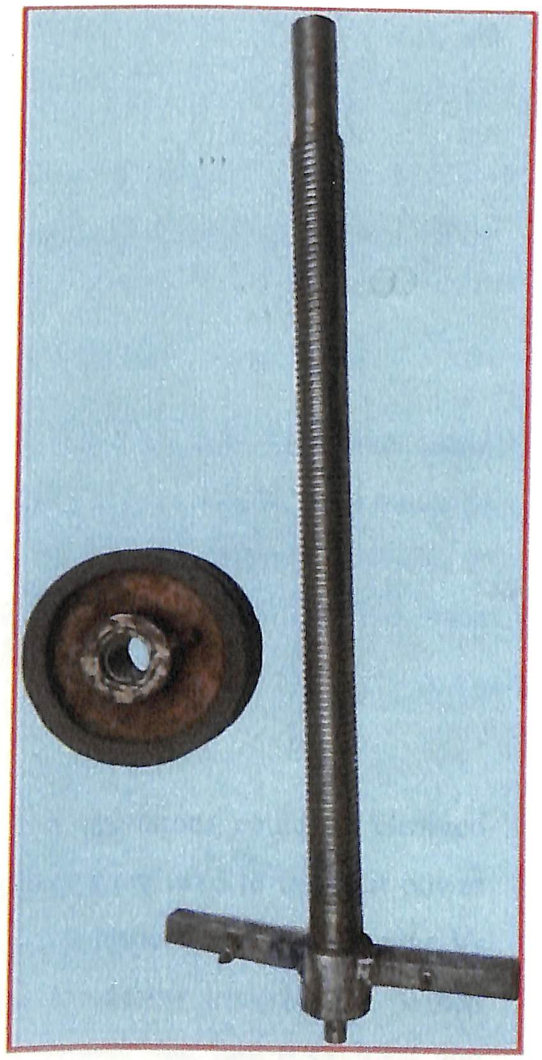

Plate 3.8 Screw shaft

All dimensions are in cm

1. Screw shaft, 2. Pulley, 3. Thrust bearing, 4. Shaft guide.

3.4.4 Power transmission unit

Transmission system was developed for proper power transmission from electric motor to peeling and cutting-coring operations of the developed machine. The power transmission system consisted of electric motor, gear box and the belt and pulley.

3.4.4.1Electric motor

The speed of jackfruit peeler cum corer machine was optimized using a 1.0 hp single phase reversible electric motor of 1425 rpm.

3.4.4.2 Speed reduction gear box

The speed of jackfruit peeler cum corer machine was optimized using reduction of speed gear box. The speed reduction gear was connected with motor to reduce the speed from 5:1 rpm and convert the horizontal rotational motion to vertical. It consisted of set of rotating gears, engine shaft and propeller shaft, each shaft having a 6 inch pulley.

3.4.4.3 Belt and pulley

The speed of the peeling and cutting-coring operations could be changed based on belt and pulley arrangement. Belt and pulley were used to transmit power from one shaft to another by means of pulleys and belts respectively. Totally nine V-grooved pulleys made up of cast iron were used for power transmission, which includes four 15.24 cm diameter, two 17.78 cm diameter and one 6.35, 12.7 and 20.32 cm diameter of pulleys respectively. The diameter of pulley was selected based on optimized speed of the developed machine. The five B-type, V-belts made up of rubber material were used for power transmission, which includes two 104.14 cm length and one 101.6 cm, 106.68 cm and 124.46 cm length of belts respectively. The length of belt was selected based on centre to centre distance between sheaves and diameters of driver and driven pulleys.

3.4.5 Frame assembly

Main frame was required to support other parts of the developed machine and to withstand against vibration during the operation. The main frame was fabricated from MS iron square channel having dimensions of 50×50×3 mm for mounting fruit holder. peeler assembly, corer assembly and power transmission system. The length, width and height of main frame were 64.5, 64.5 and 214.5 cm respectively. The peeler assembly, pillow block, gear box, core removing tool, fruit holder and electric motor were assembled on main frame using nuts and bolts.

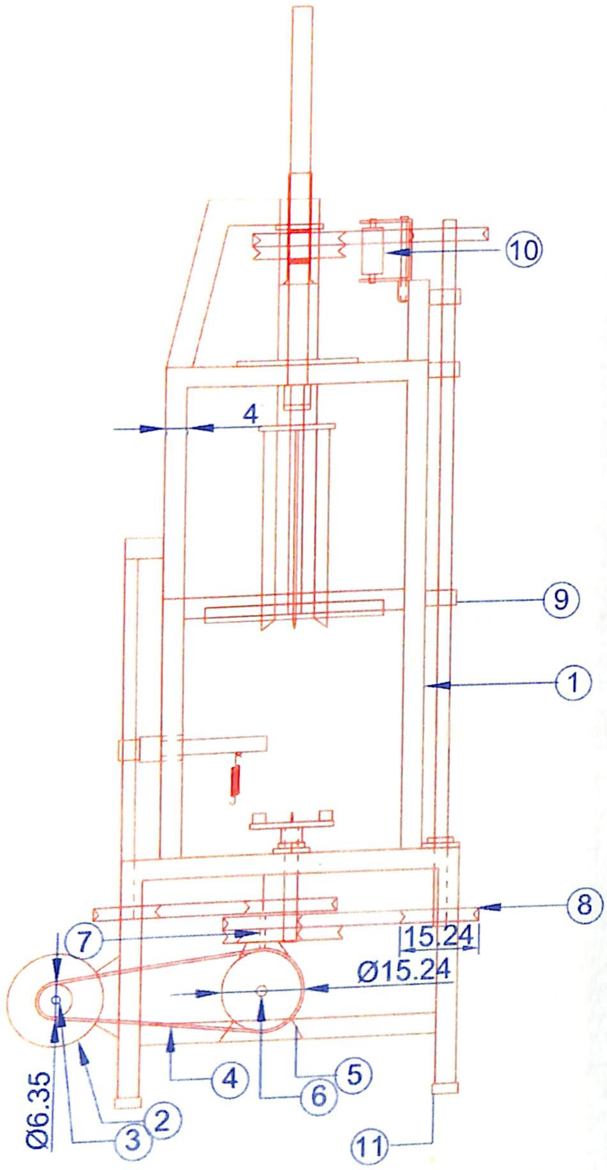

Fig. 3.9 Front view of the jackfruit peeler cum corer

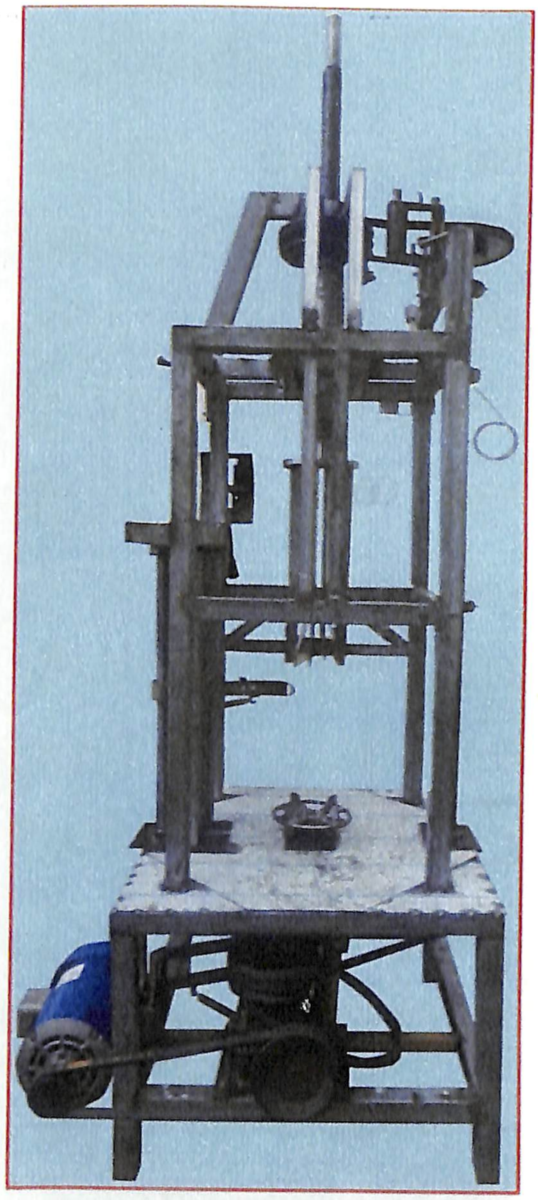

Plate 3.9 Front view of the jackfruit peeler cum corer

All dimensions are in cm

1. Frame, 2. Motor, 3. Motor shaft, 4. Belt, 5. Gear box, 6. Engine shaft, 7. Propeller shaft, 8. Pulley, 9. Pillow block, 10. Idler pulley, 11. Rubber bush

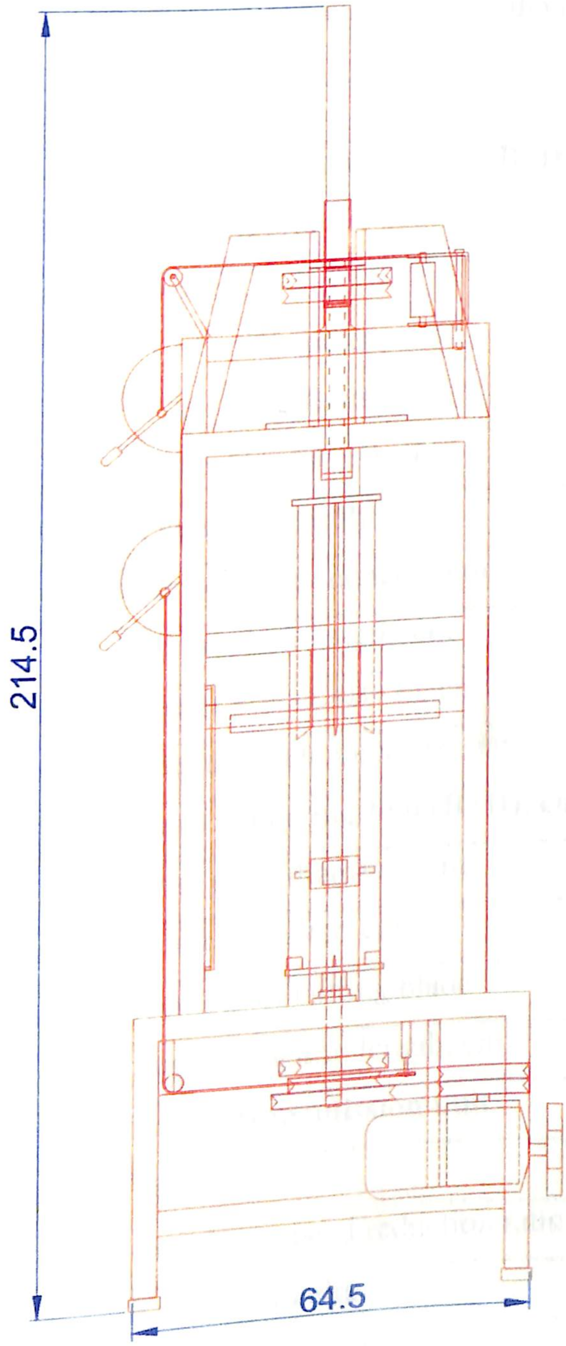

Fig. 3.10 Side view of the jackfruit peeler cum corer

All dimensions are in cm

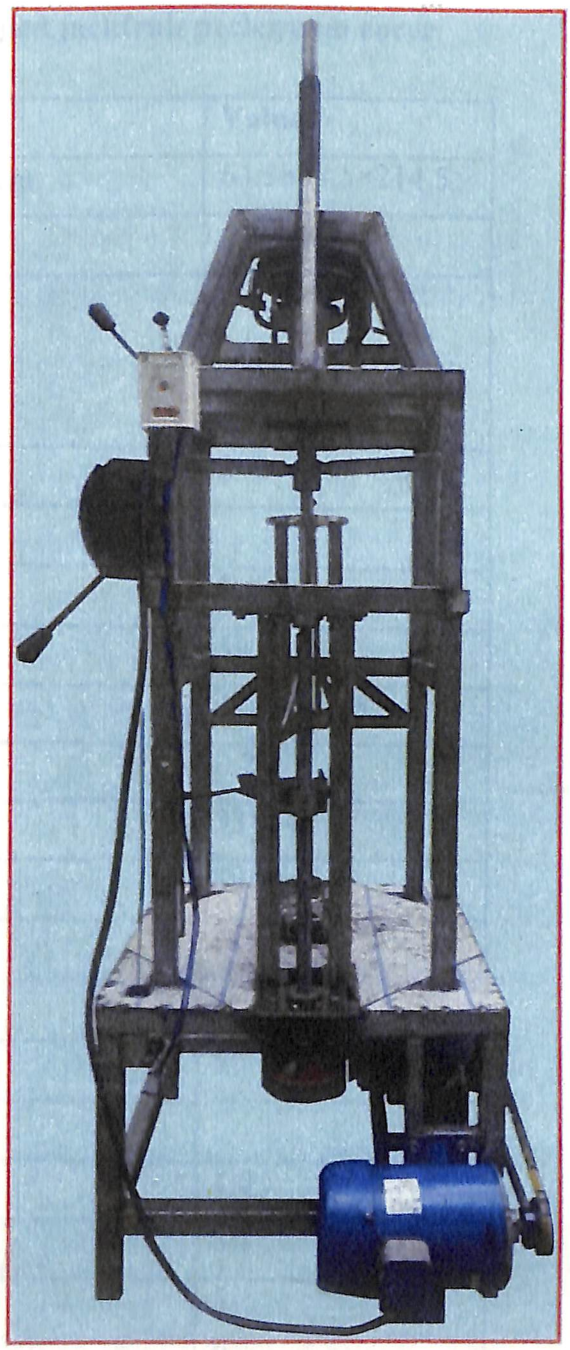

Plate 3.10 Side view of the jackfruit peeler cum corer

Table 3.1 Specifications of the newly developed jackfruit peeler cum corer

SI. NO.	Item	Values
A	**Over all dimensions (L×B×H), cm**	64.5×64.5×214.5
B	**Fruit holder**	
i.	Disc Diameter, cm Thickness, cm	 16 1
ii.	Projection (B×H), cm	2×2
C	**Peeler assembly**	
i.	Screw shaft diameter, cm	2.4
ii.	Screw shaft length, cm	59.5
iii.	Peeler arm (L×B×T), cm	17.5×3×0.5
iv.	Peeling blade thickness, cm	0.2
D	**Core removing tool (B×H), cm**	33×44
i.	Base plate diameter, cm	14.5
ii.	Corer diameter, cm	6.3
iii.	Number of cutting blade	4
iv.	Supporting arm length, cm	37
E	**Power transmission unit**	
i.	Motor, hp	1.0
ii.	Gear box, speed reduction ratio	5:1
iii.	Number of belts	5
iv.	Number of pulleys	9

3.5 Operational procedure for jackfruit peeler cum corer machine

3.5.1 Pre-preparation

The stem (top) side portion of fruit was removed manually to find out the position of the central core and the calyx (bottom) portion of the fruit was also removed to make sure that the fruit stand properly over the fruit holder as shown in Plate 3.11.

The fruit was placed on fruit holder which moves the jackfruit circularly on a horizontal plane. While loading, jackfruit was held vertically to stand on the fruit holder with correct fruit positioning to distribute the fruit load uniformly throughout surface of fruit holder at the time of peeling operation. Core removing tool was fixed properly on position of the central core by operating the motor (Plate 3.12). After loading the jackfruit between fruit holder and core remover tool, fruit was tightly holding in vertical direction.

3.5.2 Peeling operation

Motor was switched on during the peeling operation. Fruit holder was driven in a clockwise direction on a horizontal plane and simultaneously jackfruit and core removing tool were also made to rotate in the same direction. As the fruit holder rotates, it enables peeling blade to move parallel to profile of the jackfruit rotational axis (Plate 3.13). Spring pressed the peeling blade softly on the fruit profile, so that fruit was completely peeled (Plate 3.14). By changing the rotational direction of the motor shaft peeler blade was brought to its original position.

3.5.3 Cutting-coring operation

After the completion of peeling operation, the cutting-coring operation was started. Due to screw mechanism rotational motion of pulley was converted into linear movement of screw shaft which is connected with corer tool. The downward motion of screw shaft pushes the core removing tool down. Motor was operated until the core removing tool reaches the calyx of jackfruit, ensuring that the blades and corer passed completely through the jackfruit. By changing the rotational direction of the motor shaft core removing tool was moved upwards, cut core from the corer was pushed down manually by hand. The cutting-coring operation and the core removed from the whole jackfruit were shown in Plate 3.15.

3.5.4 Bulb separation

The bulb separation of four cut portion jackfruit was done manually after the completion of above operations.

3.6 Performance evaluation of a jackfruit peeler cum corer machine

3.6.1 Experimental details

The experiment was conducted as a 2 factor experiment in completely randomized design. Three sizes of jackfruit and three speeds were chosen for peeling and cutting-coring operations whose details are given below. For each experiment three replications were made. The independent and dependent variables considered in the study are given below.

3.6.1.1 Peeling operation

Independent variables	Levels	Dependent variables
(i) Jackfruit size (cm)	**3**	
(a) Small	L_1	1) Time of peeling (s)
(b) Medium	L_2	2) Peeling efficiency (%)
(c) Large	L_3	3) Bulb wastage (%)
(ii) Speed of fruitholder (rpm)	**3**	
(a) 90	R_1	
(b) 120	R_2	
(c) 150	R_3	

Plate 3.11 Trimmed jackfruit

Plate 3.12 Loading of jackfruit

Plate 3.13 Peeling operation

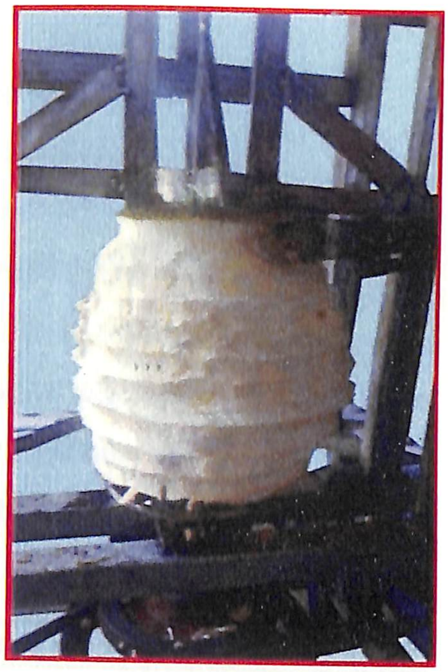

Plate 3.14 Peeled jackfruit

Plate 3.15 Cutting-coring operation of jackfruit

Where,

L_1 = Small size jackfruit (≤ 35 cm length with a diameter 20-22 cm)

L_2 = Medium size jackfruit (35-41 cm length with a diameter 22-24 cm)

L_3 = Large size jackfruit (≥41 cm length with a diameter 24-26 cm)

R_1, R_2 and R_3= 90, 120 and 150 rpm of fruit holder respectively

Angular velocity of the fruit holder and rpm of screw shaft pulley were the two parameters used during jackfruit peeling operation. The speed of fruit holder alone considered for the statistical analysis; because rotational speed of screw shaft pulley depends on fruit holder speed. The fruit holder rpm and measured rpm of screw shaft pulley details are given below.

Sl. No.	RPM of Fruit holder	Measured RPM of peeler pulley
1.	90	130
2.	120	170
3.	150	210

3.6.1.2 Coring operation

The same fruit after the peeling operation used for the cutting-coring operation. The notations used to represent the different treatments and levels are given below.

Independent variables	Levels	Dependent variables
i) Jackfruit size (cm)	**3**	
(a) Small	L_1	
(b) Medium	L_2	1) Time of coring (s)
(c) Large	L_3	2) Coring efficiency (%)
ii) Speed of corer pulley (rpm)	**3**	3) Bulb wastage (%)
(a) 110	C_1	
(b) 130	C_2	
(c) 150	C_3	

Where,

L_1 = Small size jackfruit ($\leq$ 35 cm length with a diameter 20-22 cm)

L_2 = Medium size jackfruit (35-41 cm length with a diameter 22-24 cm)

L_3 = Large size jackfruit ($\geq$41 cm length with a diameter 24-26 cm)

C_1, C_2 and C_3 = 110, 130 and 150 rpm of corer pulley respectively

3.6.2 Efficiency

3.6.2.1 Peeling efficiency

Peeling efficiency was determined as the ratio of weight of peel removed to total weight of peel. The suggested formula by Singh and Shukla (1995) was used for the calculation of the peeling efficiency.

$$\text{Peeling efficiency (\%)} = \frac{(Y-Z)}{(Y)} \times 100 \qquad \text{...3.1}$$

Where, Y = Weight of total peel on jackfruit (g)

Z = Weight of peel removed by hand trimming after mechanical peeling (g)

3.6.2.2 Coring efficiency

Coring efficiency was determined as the ratio of weight of core removed to total weight of core. The suggested formula by Singh and Shukla (1995) was used and modified for the calculation of the coring efficiency as given below.

$$\text{Coring efficiency (\%)} = \frac{(A-B)}{(A)} \times 100 \qquad \text{... 3.2}$$

Where,

A = Weight of total core in jackfruit (g)

B = Weight of core removed by hand trimming after mechanical coring (g)

3.6.3 Bulb wastage

3.6.3.1Bulb wastage during the peeling operation

The suggested formula by Jimoh and Olukunle (2012) was used and modified for the calculation of the bulb wastage (%) during the peeling operation as given below.

$$\text{Bulb wastage, \% (peeling operation)} = \frac{(W)}{(W + X)} \times 100 \quad \ldots 3.3$$

Where,

W = Weight of bulb portion obtained from the peeled produce (g)

X = Weight of separated bulb after mechanical peeling (g)

3.6.3.2 Bulb wastage during the coring operation

The suggested formula by Jimoh and Olukunle (2012) was used and modified for the calculation of the bulb wastage. The bulbs wastage (%) was calculated using the formula

$$\text{Bulb wastage, \% (coring operation)} = \frac{(C)}{(C + D)} \times 100 \quad \ldots 3.4$$

Where, C = Weight of bulb portion obtained from the cored produce (g)

D = Weight of separated bulb after mechanical coring (g)

3.6.4 Time of operation

3.6.4.1 Time of peeling operation

The time taken for peeling operation of developed machine during each combination of jackfruit size and speed was determined using a stop watch.

3.6.4.2 Time of cutting-coring operation

The time taken for cutting, coring operation of developed machine during each combination of jackfruit size and speed was determined using a stop watch.

3.7 Statistical analysis

The data obtained were statistically analyzed by 2 Factor Completely Randomized Design (CRD) using M STATS-C software. The analysis of variance (ANOVA) and mean table for different parameters were tabulated and the level of significance was reported.

3.8 Optimization of machine parameters

Optimization of machine parameters *viz.*, speed of fruit holder and speed of corer pulley was done by considering the time, efficiency and bulb wastage during peeling and coring operation.

3.8.1 Energy consumption by developed machine at optimal condition

The machine operation cost depends upon the energy consumption during the operations. Hence, it is necessary to determine the total energy requirement for operating the machine. Energy consumption for optimal condition was determined by using single phase digital energy meter (HTC PM 03 power guard, accuracy 1.0 class). Five medium size jackfruits were selected at random and subjected to peeling and cutting-coring operation. The required energy for peeling and cutting-coring operations for each sample under load and without load conditions was calculated from formula

$$\text{Total energy consumption (with load)} = (Y + Z) \qquad \ldots 3.5$$

$$\text{Total energy consumption (without load)} = (W+X) \qquad \ldots 3.6$$

Where.

Y = Energy consumption for peeling operation (kWh)

Z = Energy consumption for cutting-coring operation (kWh)

W = Energy consumption to run the peeler blade without load up to the recorded time (s) of peeling operation during loaded condition (kWh)

X = Energy consumption to run the core removing tool without load up to the recorded time (s) of cutting-coring operation during loaded condition (kWh)

3.9 Comparison of developed jackfruit peeler cum core machine with manual cutting

The experiments were conducted for optimized condition with peeler speed of 90 rpm and corer speed of 130 rpm in newly developed machine with 5-6 jackfruits (total weight of 50 kg) and the throughput, processing time were also recorded. Similarly, manual cutting and separation of bulbs was also carried out for 5-6 jackfruits (total weight of 50 kg) by employing one skilled labour and the results were compared with mechanical operation to assess the throughput and capacity. The throughput was calculated by using formula (Jimoh and Olukunle, 2012)

$$\text{Throughput (kg/h)} = \frac{\text{(Total weight of jackfruit processed, kg)}}{\text{(Processing time, h)}} \quad \ldots 3.7$$

The total processing time for mechanical operation of peeling, cutting-coring and bulb separation for each sample was recorded using stop watch. Similarly, time of manual operation was calculated by considering the cutting, coring and bulb separation time. The processing time per fruit was calculated by following formula

$$\text{Processing time (min/fruit)} = \frac{\text{(Total time of processing)}}{\text{(Number of jackfruit)}} \quad \ldots 3.8$$

3.10 Cost economics

Based on the material cost and cost of fabrication, the total cost of developed jackfruit peeler cum corer machine was worked out. The operation cost of mechanical and manual operation was worked out, by including the fixed and variable costs. The benefit-cost ratio was determined by considering cost of raw jackfruit and selling price of processed bulbs as given in Appendix C.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results of the experiments carried out for the evaluation of the newly developed peeler cum corer machine for jackfruit.

4.1 Physical properties of jackfruit

The mean, minimum and maximum values of fruit length, fruit diameter, core length, core diameter and rind thickness of the jackfruits were found out using image processing method and tabulated in Table 4.1.

4.1.1 Size

The length of the fruit and core is important for fixing the core removing tool length and height of peeler screw shaft assembly. The mean, minimum and maximum values of length of jackfruit were found as 38±7.79, 26.52 and 55.81 cm whereas the core length as 29.95±7.7, 20.23 and 48.06 cm, respectively. The present result of fruit length was found to be closer with the findings of Haq (2011), Gomez *et al.* (2015), Kalita *et al.* (2014) and Kotoky *et al.* (2014).

The mean value of core diameter was determined to fix the diameter of corer for effective separation and the maximum value of fruit diameter was used for fixing the width of core removing tool. The mean, minimum and maximum values of fruit diameter were found to be 22.67±2.55, 18.23 and 27.8 cm whereas the core diameter as 5.53±1.2, 3.99 and 9.72 cm respectively. The result of fruit diameter is in line with the findings of Gomez *et al.* (2015) and Kalita *et al.* (2014). Moreover, among the collected samples wide variability was observed for core length and diameter of jackfruit. these results are similar with the findings of Kalita *et al.* (2014).

Fruit rind thickness was found out to fix the clearance between blade and peeler arm in order to remove the peel completely from the fruit. The mean, minimum and maximum values of rind thickness were found to be 1.85±0.26, 1.59

and 2.42 cm, respectively. Variability of fruit rind thickness in the present study was found to be closer with the findings of Shyamalamma *et al.* (2014). Based on the study of linear dimensions *viz.*, diameter and length of fruit, it was revealed that mean length of jackfruit was found as 38 cm and nearly 80% of the jackfruits are falling between 20-26 cm diameters. By considering the above results jackfruit was classified into following three groups

1) Small size (L_1) : ≤ 35 cm length with a diameter of 20-22 cm

2) Medium size (L_2) : 35-41 cm length with a diameter of 22-24 cm

3) Large size (L_3) : ≥41 cm length with a diameter of 24-26 cm

Table 4.1 Physical properties of jackfruit

Physical Properties	Mean±SD	Minimum	Maximum
Fruit length (cm)	38.00±7.79	26.52	55.81
Fruit diameter (cm)	22.67±2.55	18.23	27.80
Fruit weight (kg)	8.43±2.94	5.35	16.65
Core length (cm)	29.95±7.70	20.23	48.06
Core diameter (cm)	5.53±1.20	3.99	9.72
Rind thickness (cm)	1.85±0.26	1.59	2.42

Standard deviation at 5% level of significance

4.1.2 Mass

Weight of fruit was important in determining the factor of safety distribution in designed fruit holder disc in order to withstand against maximum load during the cutting-coring operations. The weight of jackfruit varied from 5.35-16.65 kg and mean weight was found as 8.43±2.94 kg. The Similar results have been obtained by Haq (2011). Mitra and Mani (2000), Reddy *et al.* (2004) and Gomez *et al.* (2015) for fruit mass.

4.2 *Cutting strength of jackfruit*

Five numbers of jackfruit were randomly selected and the cutting strength of peeled jackfruits was found using a universal testing machine (UTM) as explained in 3.2.2 and results were tabulated in Table 4.2.

Cutting strength was important in simulation of core removing tool and fruit holder to stand with against maximum load while cutting-coring of large size of jackfruit. From the Table 4.2, it was observed that the cutting strength of jackfruits was varying from 2.5-3.5 kN and average value was found to be 2.96±0.42 kN.

Table 4.2 Cutting force of matured jackfruit

Trial	**Cutting strength, kN (average core length of fruit)**
Fruit 1	2.8
Fruit 2	3.5
Fruit 3	3.3
Fruit 4	2.5
Fruit 5	2.7
Mean±SD	**2.96±0.42**

4.3 Performance evaluation of the jackfruit peeler cum corer machine

Performance evaluation of the newly developed jackfruit peeler cum corer machine was done in the laboratory to optimize the speed of peeler and corer pulley which aim to get the better peeling and coring efficiency with minimum bulb damages. Two factors experiment in a completely randomized design (CRD) was conducted by considering these parameters.

4.3.1 Peeling operation of developed machine

The performance evaluation of the peeler of developed machine was carried out with selected jackfruit (small, medium and large) and different speed of fruit holder (90, 120 and 150 rpm). The time of peeling (s), peeling efficiency (%) and bulb wastage (%) were determined to find out the best combination of fruit size and speed.

4.3.1.1 Effect of fruit size and speed on time of peeling

From the Fig. 4.1, it was clear that as the speed increases peeling time decreases. The peeling action at 150 rpm took less time (21.82 s) in small size jackfruits and found to be ideally suitable compared to other two sized fruits. The time of peeling was maximum (50.33 s) in case of large size jackfruit for a speed of 90 rpm. Here the linear movement of the peeling blade increases with increasing speed which leads to faster operation. In case of fruit size, with increase in size peeling time also increases because of higher fruit length and circumference. Thongsroy and Klajring (2015) reported that, time of peeling for papaya and cantaloupe fruit was found to be 23.43 and 22.69 s/fruit respectively in newly developed fruit peeling machine.

The peeling time for each variables were found to be significant ($p<0.01$) and the interaction between fruit size and speed was not significant. The results of statistical analysis were shown in Appendix A (Table A.1).

4.3.1.2 Effect of fruit size and speed on peeling efficiency

The peeling efficiency of developed machine was calculated by using the equation 3.1. From the Fig. 4.2, it was observed that, peeling efficiency was highest (85.27%) in small size fruits for a speed of 90 rpm whereas, lowest (69.59%) in case of large size fruits for a speed 150 rpm. Here, peeling efficiency of the developed machine decreases with increasing speed due to the non-uniform movement of peeling blades at higher RPM. The decreasing trend in peeling efficiency with an increasing fruit size is due to higher rind thickness. Another reason is that with increasing fruit size, diameter also increases which lead to variation in angle of contact between peeling blade and fruit surface. The results of statistical analysis were shown in Appendix A (Table A.2). The peeling efficiency for each variables were found to be significant ($p<0.01$) and the interaction between fruit size and speed was not significant.

4.3.1.3 Effect of fruit size and speed on bulb wastage during peeling operation

The bulb wastage (%) during the peeling operation of developed machine was calculated by using the equation 3.3. The highest bulb wastage (17.64%) was observed in small size fruits at 150 rpm whereas, lowest (6.20%) was for large size fruit at 90 rpm as shown in Fig. 4.3.

From this study it is observed that as the speed increases, bulb wastage increases and this may be due to non-uniform movement of peeling blade at higher speed. But as the fruit size increases wastage decreases there by affecting the angle of contact between blade and fruit surface. This higher fruit size is also affecting the clearance between peeling blade and end of the peeler arm because of higher rind thickness. Singh *et al*, (2013) developed a pineapple peeler cum slicer and peeling efficiency for the same was 97.2 % with flesh wastage of 5.3%.

The results of statistical analysis were shown in Appendix A (Table A.3). The effect of fruit size and speed on bulb wastage (%) were found to be significant ($p<0.01$).

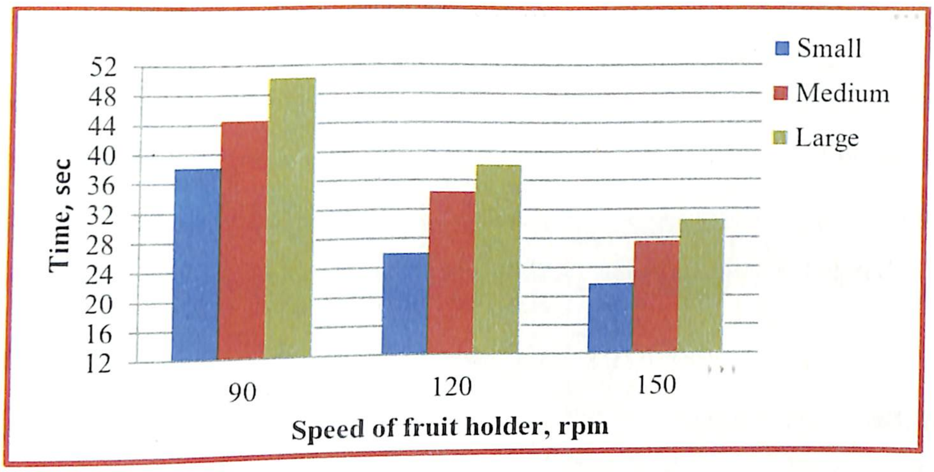

Fig. 4.1 Effect of fruit size and speed on time of peeling

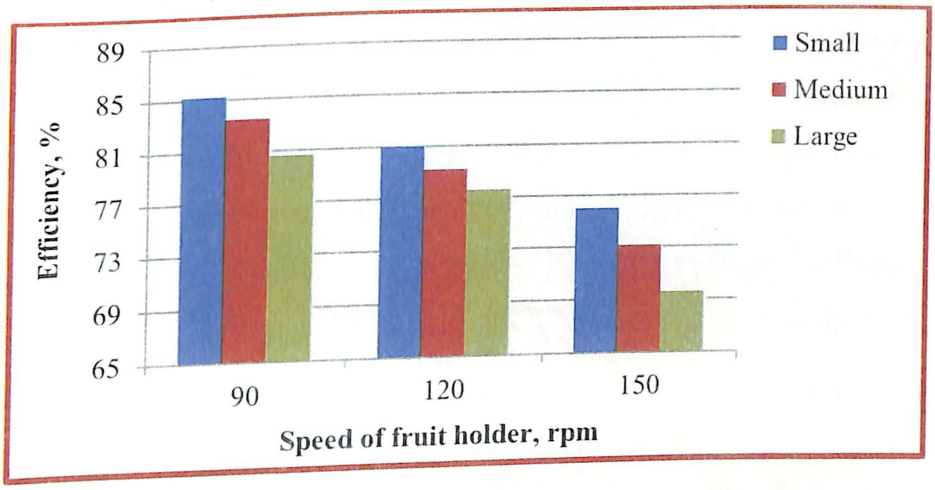

Fig. 4.2 Effect of fruit size and speed on peeling efficiency

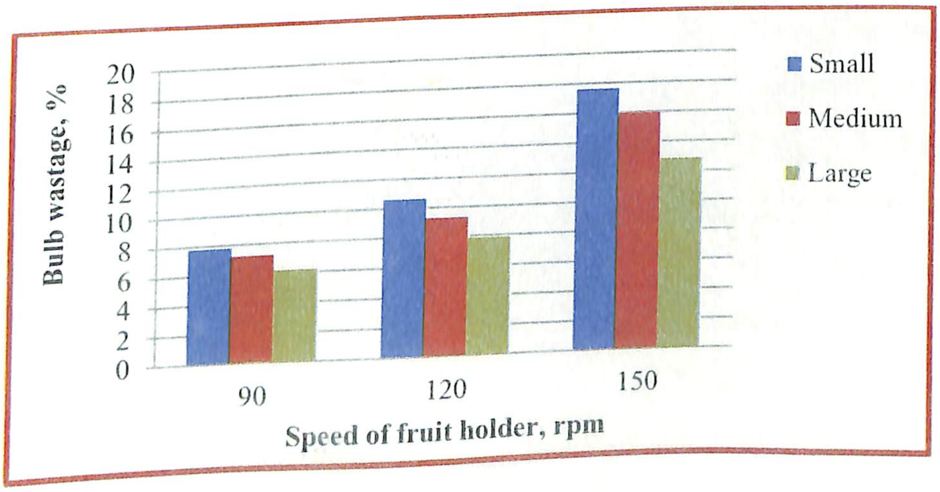

Fig. 4.3 Effect of fruit size and speed on bulb wastage

4.3.2 Coring operation of developed machine

The performance evaluation of coring operation of developed machine was carried out with fruit size (small, medium and large) and speed of corer pulley (110, 130 and 150 rpm). The time of coring (s), coring efficiency (%) and bulb wastage (%) was also determined to find out the best combination of fruit size and speed.

4.3.2.1 Effect of fruit size and speed on cutting-coring time

The time taken for cutting-coring operation of developed machine with combinations of speed and fruit size is presented in Fig. 4.4 and Table 4.4. It is observed that time of cutting-coring was found minimum (15.44 s) in small size jackfruits at a speed of 150 rpm and maximum (29.92 s) in case of large size jackfruit at a speed 110 rpm. Here the linear movement of the core removing tool increases with increasing speed which leads to faster operation. The increasing trend in time of cutting-coring with an increasing fruit size is due to higher fruit length. The time of cutting-coring for each variables were found to be significant ($p<0.01$) and the interaction between size and speed was not significant. The results of statistical analysis were shown in Appendix B (Table B.1).

4.3.2.1 Effect of fruit size and speed on coring efficiency

The coring efficiency of developed machine was calculated by using the equation 3.2. The maximum coring efficiency (93.23%) was observed in small size fruits at speed of 110 rpm, followed by 130 rpm (92.85%) whereas, minimum (72.64%) was observed in large size fruit at speed of 150 rpm (Fig. 4.5). The result indicates that in case of speed, higher coring efficiency is found at 110 and 130 rpm which is closer and lesser efficiency for higher rpm that is 150. This is due to the reason of moving of fruit sideways at higher rpm which leads to reduction in efficiency. So a machine speed of 130 rpm is recommended for this coring mechanism. In case of fruit size, with increase in size there is decrease in efficiency because of high core diameter. The coring efficiency for each variables were found to be significant ($p<0.01$) and the interaction between size and speed was not significant. The results of statistical analysis were shown in Appendix B (Table B.2).

4.3.2.1 Effect of fruit size and speed on bulb wastage

The bulb wastage during the coring operation of developed machine was calculated by using the equation 3.4. The highest bulb wastage was found to be 14.04% for small size fruit at a speed of 150 rpm and lowest 6.09% for large fruit at 130 rpm, followed by 6.64% for 110 rpm as given in Fig. 4.6. The bulb wastage decreases if the speed of operation decreases. This is due to the fact that as the speed increases, sideways movement of fruit starts which cut the bulbs there by increases the bulb wastage. But, in case of lower rpm (110 and 130 rpm) there is no sideways movement of fruit so that machine speed of 130 rpm is the critical speed and if the speed exceeds then the sideways movement of the fruit will occur. In case of fruit size for minimum bulb wastage, it is recommended here larger fruit size because of high core diameter. The bulb wastage (%) for each variables were found to be significant ($p<0.01$) and the interaction between size and speed was not significant. The results of statistical analysis were shown in Appendix B (Table B.3).

Similar testing results were recorded for Nickhil (2015) newly fabricated mechanical tool to separate the bulbs from whole jackfruit. The results shows that, the developed tool was found to operate with maximum core removing efficiency of 96.00% in small fruits for a speed of 600 rpm and minimum (71.33%) in case of large size fruit at 800 rpm. The highest bulb wastage (12.20%) was found in small size fruit at a speed of 600 rpm and lowest (3.83%) was for large fruit at 600 rpm. The time of core removing was found maximum (156.33 sec) in large size fruit for a speed of 600 rpm whereas, minimum (44.33 sec) in case of small size fruit at 800 rpm.

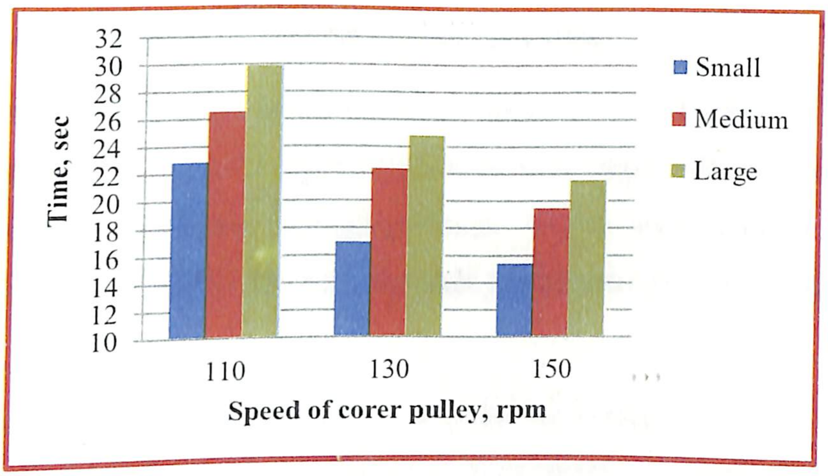

Fig. 4.4 Effect of fruit size and speed on time of cutting-coring

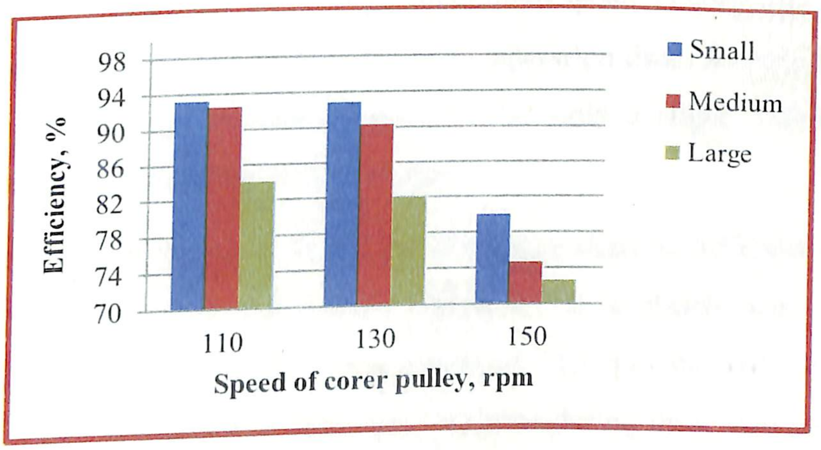

Fig. 4.5 Effect of fruit size and speed on coring efficiency

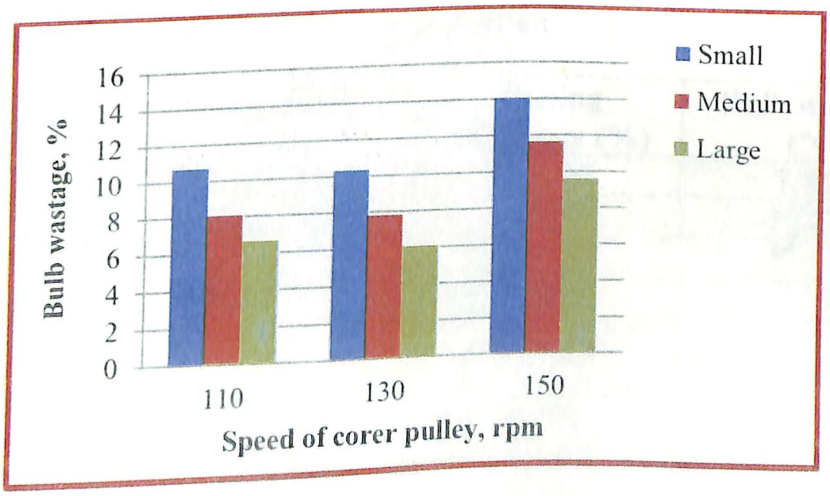

Fig. 4.6 Effect of fruit size and speed on bulb wastage

4.4 Optimisation of peeling and cutting-coring operation

Optimisation of machine parameters *i.e.*, speed of fruit holder and speed of corer pulley was done by considering the minimum time, high efficiency and lowest bulb wastage during peeling and coring operation. As per above consideration, 90 rpm and 130 rpm was found to be best for fruit holder and of corer pulley speed, respectively.

From the Table 4.3, it was observed that, peeling operation at 90 rpm showed minimum bulb wastage for small, medium and large sized fruits with high peeling efficiency of 85.27%, 83.51% and 80.64% respectively with increasing trend in case of time of operation. For indicating the ideal operational speed, peeling efficiency and bulb wastage were the most important factors than operation time. So time of peeling was given less consideration in this operation. Also only a slight difference was observed between peeling time for 90 to 120 rpm.

Cutting-coring operation of peeled jackfruit was done at different operating speed of 110, 130 and 150 rpm. From the Table 4.4, it is clearly seen that even though coring efficiency is maximum at a speed of 110 rpm the bulb wastage is minimum at 130 rpm irrespective of fruit size. By considering these two parameters, machine works at 130 rpm may be considered as optimal.

Table 4.3 Optimisation of speed of peeling operation

Sl. No.	Treatment	Time of peeling (s)	Peeling efficiency (%)	Bulb wastage (%)
1	L_1R_1	38.247	85.273	7.853
2	L_1R_2	26.083	81.050	10.643
3	L_1R_3	21.820	76.020	17.647
4	L_2R_1	44.577	83.513	7.247
5	L_2R_2	34.463	79.240	9.310
6	L_2R_3	27.590	73.137	15.983
7	L_3R_1	50.337	80.640	6.207
8	L_3R_2	38.250	77.603	7.907
9	L_3R_3	30.543	69.590	12.853

Where, L_1R_1= small fruit and 90 rpm, L_1R_2= small fruit and 120 rpm, L_1R_3= small fruit and 150 rpm, L_2R_1= medium fruit and 90 rpm, L_2R_2= medium jackfruit and 120 rpm, L_2R_3= medium fruit and 150 rpm, L_3R_1= large fruit and 90 rpm, L_3R_2= large fruit and 120 rpm and L_3R_3=large fruit and 150 rpm.

Table 4.4 Optimisation of speed of coring-cutting operation

SI. No.	Treatment	Time of cutting-coring (s)	Coring efficiency (%)	Bulb wastage (%)
1	L_1C_1	22.873	93.230	10.720
2	L_1C_2	16.983	92.850	10.337
3	L_1C_3	15.440	80.011	14.040
4	L_2C_1	26.547	92.513	8.070
5	L_2C_2	22.390	90.320	7.810
6	L_2C_3	19.500	74.667	11.673
7	L_3C_1	29.920	84.09	6.647
8	L_3C_2	24.833	82.032	6.090
9	L_3C_3	21.550	72.647	9.623

Where, L_1C_1= small fruit and 110 rpm, L_1C_2= small fruit and 130 rpm, L_1C_3= small fruit and 150 rpm, L_2C_1= medium fruit and 110 rpm, L_2C_2= medium jackfruit and 130 rpm, L_2C_3= medium fruit and 150 rpm, L_3C_1= large fruit and 110 rpm, L_3C_2= large fruit and 130 rpm and L_3C_3=large fruit and 150 rpm

4.4.1 Energy consumption

The energy consumption of newly developed machine during without load and full load conditions were found out using a digital energy meter connected in series with the motor and the energy was calculated by the equation 3.6 and 3.5 respectively, and the corresponding results are tabulated in Table 4.5. The machine was operated at the optimized condition of peeling speed (90 rpm) and cutting-coring speed (130 rpm) for medium sized jackfruit. The power consumption varies from 0.0105-0.0177 kWh/fruit at full load condition whereas 0.0094-0.0114 kWh/fruit without load. The average power consumption for loaded condition was found as

0.0149±0.0029 kWh/fruit whereas in without load condition it was found to be 0.0104±0.0007 kWh/fruit.

Table 4.5 Power requirement of newly developed jackfruit peeler cum corer machine

SI NO	Without load (kWh)	Full load (kWh)
1	0.0094	0.0123
2	0.0105	0.0105
3	0.0108	0.0108
4	0.0102	0.0138
5	0.0114	0.0177
Mean±SD	**0.0104±0.00074**	**0.0149±0.0029**

4.5 Comparison study of jackfruit peeler cum core machine with the traditional method of manual cutting

The experiments were conducted for comparison study with jackfruit peeler cum core machine with the traditional method of manual cutting for 5-6 jackfruit with an average weight of 50 kg and the throughput, processing time were also recorded.

As shown in Appendix C, the average time taken for peeling, cutting-coring and bulb separation was maximum (28.80 min/fruit) during manual operation and in case of mechanical operation, it was only 13.30 min/fruit, which is lesser then manual operation. The maximum throughput of machine was 37.59 kg/h, whereas in manual operation, it was 17.36 kg/h.

4.6 Cost economics

The cost of the developed jackfruit peeler cum corer machine was Rs. 46950 which comprises of the material and fabrication cost. The total hourly operational cost of the machine was Rs. 52.97 which included the fixed cost (Rs. 8.35) and the variable cost (Rs. 44.62) whereas, in manual operation the hourly operational cost was Rs. 47.5.

The fixed cost of the machine consisted of depreciation (Rs. 4.40/h), the interest (Rs. 3.22/h) and insurance, shelter etc. (Rs. 0.73/h). While the variable cost includes worker wages Rs. 37.5/h, repair and maintenance cost Rs. 2.44/h, energy charges Rs. 0.484/h and cost of coconut oil Rs. 4.2/h. The benefit-cost ratio of the developed machine was 2.32:1.00 and in case of manual operation it was 2.66:1.00.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Jackfruit (*Artocarpus heterophyllus*) belongs to the family Moraceae which is popular and important underutilized fruit. India is the largest producer of jackfruit, with a total cultivated area and production (2013-14) of 1,58,000 ha and 1.573 MT respectively. In Kerala, jackfruit is cultivated in an area of about 90,225 ha with a production of about 294 million fruits per year. The jackfruit is a nutritional fruit rich in many vitamins, nutrients and also having anti-cancer properties.

At present, demand for jackfruit is increasing day by day owing to its availability, sweetness and nutritional composition. Diversified value added products for consumption among all age group of consumers is needed. Sensitized growers, entrepreneurs and volunteers may focus more on jackfruit value added products. But traditional manual peeling, coring and cutting is time consuming and labour intensive process. Moreover, the latex of this fruit also causing hindrance during separation of fruit bulb for consumption. The tedium in manual processing is the major reason for the underutilization of this fruit. Thus effective mechanization for this process is a need of the hour.

Matured, unripe jackfruits (*cv.* Varikka) harvested from the instructional farm of K.C.A.E.T, Tavanur were used for the study. Fruits of only oblong/round shapes were harvested from the selected trees. Before the fabrication of the machine, the selected physical and mechanical properties were studied.

The length of fruit and core is important for fixing the corer tool length and height of peeler screw shaft assembly. Mean value of core diameter was determined to fix the diameter of corer for effective separation and the maximum fruit diameter was used for fixing the width of core removing tool. Fruit rind thickness was found out to fix the clearance between blade and peeler arm in order to remove the peel completely from the fruit. Based on the study of fruit linear dimension (diameter and length) fruit was classified into small, medium and large. Weight of fruit was important in design and fabrication of fruit holder disc. The cutting strength of peeled jackfruit was found to determine factor of safety distribution in designed and fabricated core removing tool and fruit holder disc in order to withstand against maximum bending stress.

Based on the preliminary studies, peeler cum corer machine for jackfruit was conceptualized, designed and fabricated. The major components of the machine are fruit holder. peeler assembly, corer assembly along with cutting mechanism, power transmission unit and frame assembly.

The working principle of peeling operation is, as the jackfruit rotates, peeling was done helically due to the linear motion of the blade from bottom to top. Similarly cutting-coring operation was performed by converting the rotary motion of pulley into linear motion with the help of screw mechanism. During cutting-coring operation core removing tool which is attached to the screw shaft was pressed against the fruit. The bulbs separation of four cut portion jackfruit was done manually after the completion of above operations.

Performance evaluation of the machine was conducted in the laboratory to optimize the speed of peeling and coring with minimum bulb damages. The peeling action at 150 rpm took less time (21.82 s) in small size jackfruits and found to be ideally suitable compared to other three sized fruits. The time of peeling was maximum (50.33 s) in case of large size jackfruit for a speed of 90 rpm. The peeling efficiency was highest (85.27%) in small size fruits for a speed of 90 rpm whereas, lowest (69.59%) in case of large size fruits for a speed 150 rpm. The highest bulb wastage (17.64%) was observed in small size fruits at 150 rpm whereas, lowest (6.20%) was for large size fruit at 90 rpm.

The time of cutting-coring was found minimum (15.44 s) in small size jackfruits at a speed of 150 rpm and maximum (29.92 s) in case of large size jackfruit at a speed 110 rpm. The maximum coring efficiency (93.23%) was observed in small size fruits at speed of 110 rpm, followed by 130 rpm (92.85%) whereas, minimum (72.64%) was observed in large size fruit at speed of 150 rpm. The highest bulb wastage was found to be 14.04% for small size fruit at a speed of 150 rpm and lowest 6.09% for large fruit at 130 rpm, followed by 6.64% for 110 rpm. Tested parameters (fruit size, speed of fruit holder and corer) were statistically significant for individual parameter whereas, interaction was not significant in case of time and efficiency.

Optimisation of machine parameters (speed of fruit holder and speed of corer pulley) was done by considering efficiency, bulb wastage and time requirement. Speed of 90 rpm and 130 rpm was found to be optimal for fruit holder and corer pulley, in respect of minimum time, higher efficiency and lowest bulb wastage. Power requirement for optimized parameter with load is 0.0149 kWh/fruit and without load is 0.0104 kWh/fruit.

Comparative study of manual method of cutting, coring with the developed jackfruit peeler cum core machine was carried out by considering throughput and total time. The maximum throughput of machine was 37.59 kg/h whereas in manual operation 17.36 kg/h which is lesser than the mechanical operation. The average taken time for peeling, coring, cutting and bulb separation was maximum (28.8 min/fruit) in manual operation and in case of mechanical operation (13.3 min/fruit), which is lesser than manual operation. This indicated that the developed machine aids in faster cutting of jackfruits with least drudgery besides more efficient and also could be used in small and medium scale industry.

The cost of the developed machine was Rs. 46950/-. The operational cost of machine was Rs.52.97/h, which included the fixed and variable costs and in manual operation Rs.47.5/h. The benefit-cost ratio of machine was calculated as 2.32:1.00 and for manual operation 2.66:1.00.

References

REFERENCES

Agrawal. H., Sharma, P., Piyush Tiwari, R.V., Taiwade., and Dayal, R.K. 2014. Evaluation of self-healing behavior of AISI 304 stainless steel. *Trans. Indian Inst. Metals.* 15(3): 36-45.

Agrawal. Y.C., Hiran, A., and Galundia, A.S. 1987. Ginger peeling machine parameters. *Agric. Mechanization Asia Africa Latin Am.* 18(2): 59-62.

Agrawal. Y.C., Singhvi, A., and Sodhi, R.S. 1983. Development of an abrasive brush-type ginger peeling machine. *J. Agric. Eng.* 384(11): 179-182.

Agricultural statistics. 2015. Department of economics and statistics Thiruvananthapuram, Kerala.

Akhila, B.G. and Shareena, K.P. 2009. Product diversification of jackfruit (*Artocarpus heterophyllus Lam.*). B.Tech (Ag) project, Kerala Agricultural University, Thissur, 50p.

Ambrish. G.S. 2005. Design and development of an equipment for anola fruit seed remover and studies on value addition through osmotic dehydration. Unpublished M.E. (Ag. Eng.) thesis, Tamilnadu Agricultural University, Coimbatore, India.

Anonymous. 2015. Jackfruit peeling machine, *Fruit Peeler Master*. Available: https.//www.youtube.com watch?v=MijbvKZTmwc [30.01.2015].

APAARI [Asia-Pacific Association of Agricultural Research Institutions]. Jackfruit improvement in the Asia-Pacific region- A status report. 2012. Bangkok, Thailand. 182p.

Arkroyd. W.R., Gopalan, C., and Balasubramaniyam, S.C. 1966. *The nutritive value of Indian food and the planning of satisfaction diet*. Indian council of Medical Research, New Delhi, 412p.

Azad. A.K. 1989. Studies on floral biology, pattern of fruit set and quality of fruit borne in different sections of jackfruit plants. M.Sc. (Ag.) thesis. Faculty of Agriculture, BAU, Mymensingh, Bangladesh. 77p.

Azad, A.K. 2000. Genetic diversity of jackfruit in Bangladesh and development of propagation methods. Ph.D. thesis. University of southampton, UK, 275p.

Best. J.J. and Kennedy, T.J. 2005. Slicing apparatus including rotatably attached rigid blade and roller. United States Patent No. 0262703. Available: http://www.freepatentsonline.com/y2005/0262703.html

Chakespari, A.G., Rajabipour, A., and Mobli, H. 2010. Mass modeling of two apple varieties by geometrical attributes. *Austrailian J. Agric. Eng.* 1(3): 112-118.

Coady, J., Eng, P., McKenna, M., and Eng, P. 2000. Good manufacturing and material selection in the design and fabrication of food processing equipment. By Engineers Egde.

Cohen, M.L. and Siegel, J. 1994. Fruit and vegetable peeler. United States Patent No. 5279035. Available: http://www.freepatentsonline.com/5279035.html

Crane. J.H., Balerdi, C., and Maguire, I. 2005. Jackfruit growing in the Florida home landscape. Florida cooperative extension service, University of Florida. Fact sheet HS-882. 1-10.

Elevitch. C.R. and Manner, H.I. 2006. *Artocarpus heterophyllus* (jackfruit). In: Species profiles for Pacific Island agro forestry. www.traditionaltree.org

Emadi, B. 2005. Experimental studies and modelling of innovative peeling process for tough-skinned vegetables. Ph.D. thesis. Queensland University of Technology, Brisbane, 50-53.

Emadi. B., Abbaspour-Fard, M.H., and Yarlagadda, P.K.D.V. 2008. Mechanical peeling of pumpkins. Part 1: Using an abrasive-cutter brush. *J. Fd. Engg.* 89: 448-452.

Ewald, H.H. 1986. Apple corer with a core remover. United States Patent No. 4596073. Available: http://www.freepatentsonline.com/4596073.html

Ganesan. V. 1995. Design and development of a coconut dehusker. *Philipp. J. coconut stud.* 20(12): 29-32.

Gingras. M. 2001. Apparatus for peeling and optionally cutting vegetables. United States Patent No. 6253670. Available: http://www.freepatentsonline.com/6253670.html

Gomez. S., Joseph, P.M., Sheela, K.B., Sruthi, C.V., and Lal, L. 2015. Variability in fruiting season and quality attributes of jackfruit (*Artocarpus heterophyllus Lam.*) accessions in Kerala. *Int. J. Trop. Agric.* 33(2): 1249-1255.

Gunasena. H.P.M., Ariyadasa, K.P., Wikramasinghe, A., Herath, H.M.W., Wikramasinghe, P., and Rajakaruna, S.B. 1996. *Manual of jack cultivation in Sri Lanka.* Forest Information Service, Forest Department. 48.

Haq, N. 2011. Genetic resources and crop improvement in the jackfruit. Thottappilly G, Peter KV and Valavi SG, ed., Studium Press India Pvt. Ltd, New Delhi.

Harding, G.J. 2001. Peeler for fruits and vegetables. United States Patent No. 6324969. Available: http://www.freepatentsonline.com/6324969.html

He, S.L. and Tardif, P. 2000. Vegetable peeling apparatus. United States Patent No. D422173. Available: http://www.freepatentsonline.com/D422173.html

Ientile, T. 2013. Geared melon peeler. United States Patent No. 20130047444A1. Available: http://www.freepatentsonline.com/y2013/0047444.html

Jagadeesh, S.L., Reddy, B.S., Basavaraj, N., Swamy, G.S.K., Gorbal, K., Hegde, L., Raghavan, G.S.V., and Kajjidoni, S.T. 2007. Inter tree variability for fruit quality in jackfruit selections of Western Ghats of India. *Scientia Horticulturae*. 112: 382-387.

Jagadeesh. S.L., Reddy, B.S., Swamy, G.S.K., Gorbal, k., Hegde, L., and Raghavan, G.S.V. 2007. Chemical composition of jackfruit (*Artocarpus heterophyllus Lam.*) selections of Western Ghats of India. *Fd. Chem.* 102: 361-365.

Jahromi. K.M., Rafiee, S., Jafari, A., Ghasemi Bousejin, M.R., Mirasheh., R., and Mohtasebi, S.S. 2008. Some physical properties of date fruit (*cv. Dairi*). *Int. Agrophy.* 22: 221-224.

Jain. N.K., Doharey, D.S., and Sharma, K.C. 2007. Development of abrasive peeler cum polisher for ginger. *J. Agric. Engg.* 44 (3): 84-86.

Jha. S.N., Kingsly, A.R.P., and Chopra, S. 2006. Physical and mechanical properties of mango during growth and storage for determination of maturity. *J. Fd. Engg.* 72: 73-76.

Jannatizadeh, A., Naderi Boldaji, M., Fatahi, R., Ghasemi Varnamkhasti, M., and Tabatabaeefar, A. 2008. Some postharvest physical properties of Iranian apricot (*Prunus armeniaca L*). *Int. Agrophy.* 22: 125-131.

Jellesen. M.S., Rasmussen, A.A., and Hilbert, L.R. 2006. A review of metal release in the food industry, Materials and corrosion. 5: 387-393.

Jimoh. M.O. and Olukunle, O.J. 2012. An automated cassava peeling system for the enhancement of food security in Nigeria. *Nigerian Fd. J.* 30 (2): 73-79.

Jullien. C.. Benezech, T., Carpentier, B., Lebret, V., and Faille, C. 2002. Identification of surface characteristics relevant to the hygienic status of stainless steel for the food industry. *J. Fd. Engg.* 56: 77-87.

Kalita, D.N., Deka, B., Sonowal, P., and Bhagawati, M. 2014. Assessment of morphological characters of Jackfruit in lower and central Brahmaputra valley zone and North bank plains of Assam. *I. Symp. Jackfruit Breadfruit Tropics.* 21-33.

Kim, S.S. 2006. Fruits peeler. United States Patent No. US20060042097. Available: http://www.freepatentsonline.com/y2006/0042097.html

Kittur, B.H., Manjunatha, G.O., and Rajeshwari, N. 2015. Poor man's fruit: a comprehensive review on jack. *J. Plant Dev. Sci.* 7 (1): 7-12.

Kotoky, U., Saikia, I., Gogoi. Baruah, B., Baruah, S., and Bhuyan, P. 2014. Qualitative traits of jackfruit genotypes of Assam. *I. Symp. Jackfruit Breadfruit Tropics.* 40-43.

Lino, A.C.L., Sanches, J., Maria, I., and Fabbro, I.M.D. 2008. Bragantia, Campinas. 67 (3): 785-789.

Manjeshwar, S.B., Arnadi, R.S., Raghavendra, H., Jerome, D., and Harshith, P.B. 2011. Phytochemistry, nutritional and pharmacological properties of *Artocarpus heterophyllus Lam* (jackfruit): A review. *Fd. Res. Int.* 44(7): 1800-1811.

Martin, R. 2000. Fruit peeler. United States Patent No. 6125744. Available: http://www.freepatentsonline.com/6125744.html

Mitra, S.K. and Mani, D. 2000. Conservation and utilization of genetic resources in jackfruit (*Artocarpus heterophyllus L*) - a potential underutilized fruit. *Acta Horticulturae*. 523: 229-232.

Mohan, A. 2012. Development and evaluation of a seed extractor for ash gourd and cucumber. Un published M.Tech.(Ag. Eng) thesis, Kerala Agricultural University, Thrissur, 39p.

Morton, J.F. (1987). Fruits of warm climates. : Creative Resources Systems, Inc. 58-64.

Nachegowda, V., Rajesh, A.M., and Shyamalamma, S. 2014. High density orchard in jackfruit and its relevance to dry land area. *I. Symp. Jackfruit Breadfruit Tropics.* 76-81.

Narasimham, P. 1990. Breadfruit and jackfruit. In: Nagy, S., Shaw, P.E. and Wordowski, W.F. (Eds.). *Fruits of Tropical and Sub-tropical origin-Composition, Properties and Uses*. Florida Science Source, Inc: 193- 259.

National Horticulture Board - Horticultural statistics at a glance. 2015. Oxford university press publication, New Delhi, India.

Odigboh. E.U. 1976. A cassava peeling machine: Development, design and construction. *J. Agric. Engg. Res*. 21: 361-369.

Ohwovoriole, E.N., Oboli, S., and Mgbeke, A.C.C. 1988. Studies on preliminary design for a cassava tuber peeling machine. *Trans. Am. Soc. Agric. Engg*. 380-385.

Owolarafe, O.K. and Shotonde, H.O. 2004. Some physical properties of fresh okro fruit. *J. Fd. Engg*. 63 (3): 299-302.

Pattenden, J.M. 2011. Tool to pierce and split a coconut. United States Patent No. 7959967B2. Available: http://www.freepatentsonline.com/7959967.html

Pradeepkumar, T. and Kumar, P. 2008. Management of horticultural crops. Horticulture Science Series, Vol.11. New India Publishing Agency 101, Vikas Surya Plaza, New Delhi. 81-84.

Prakash, O., Kumar, R., Misha, A., and Gupta, R. 2009. *Artocarpus heterophyllus* (Jackfruit): An overview. *Pharmaccognosy Rev*. 3: 353-358.

Priya, S.D., Devisunetra, T., Mathala, J.G., Thangam, M., and Singh, P.N. 2014. A guide on jackfruit cultivation and value addition. *Technical Bulletin No. 41*, ICAR (RC), Goa.

Protte, C. 1999. Peeling machine. United States Patent No. 5857404. Available: http://www.freepatentsonline.com/5857404.html

Rafiee, S., Jahromi, K.M., Jafari, A., Sharifi, M., Mirasheh, R., and Mobli, H. 2007. Determining some physical properties of bergamot (*Citrus medica*). *Int. Agrophy.* 21: 293-297.

Rahman, A.K.M.M., Huq, E., Mian, A.J., and Chesson, A. 1995. Microscopic and chemical changes occurring during the ripening of two forms of jackfruit (*Artocarpus heterophyllus L.*). *Fd. Chem.* 52: 405-410.

Rais, M. and Sheoran, A. 2015. Scope of supply chain management in fruits and vegetables in India. *J. Fd. Process Technol.* 6 (3): 105-112.

Ranganna, B., 2014, Research and development on jackfruit value addition at UAS, Bangalore. *I. Symp. Jackfruit Breadfruit Tropics.* 108-110.

Reddy, B.M.C., Patil, P., Kumar, S.S., and Govindaraju, L.R. 2004. Studies on physico-chemical characteristics of jackfruit clones of south Karnataka. *Karnataka J. Agri. Sci.* 17 (2): 279-282.

Ridler, D.G. 2001. Fruit and vegetable peeler. United States Patent No. 6327971. Available: http://www.freepatentsonline.com/6327971.html

Rose, E.D., Rafael, San., and Calif. 1987. Apparatus for peeling pineapples. United States Patent No. 4653393. Available: http://www.freepatentsonline.com/4653393.html

Sahay, K.M. and Singh, K.K. 1994. Drying in unit operations of agricultural processing. Vikas publishing house private limited, New Delhi. 107.

Shamsudin, R., Daud, W.R.W., Takrif, M.S., and Hassan, O. 2009. Physico-mechanical properties of the josapine pineapple fruits. *Pertanika. J. Sci. Technol.* 17 (1): 117-123.

Sharifi, M., Rafiee, S., Keyhani, A., Jafari, A., Mobli, H., Rajabipour, A., and Ahram, A. 2007. Some physical properties of orange (*var. Thompson*). *Int. Agrophysics.* 21: 391-397.

Sharma, R., Mohan, N.K., and Nath, J.C. 1997. Evaluation of field potential and physicochemical composition of some local types of jackfruit. *Hort. J.* 10: 23-30.

Shyamalamma, S., Priyanka, S., Bhaskarareddy, D.V., Ramya, K.G., Veena, R., Munishamanna, K.B., and Kalpana, B. 2014. Genetic diversity assessment in selected genotypes of jackfruit in Bangalore and Tumkur districts of Karnataka. *I. Symp. Jackfruit Breadfruit Tropics.* 82-88.

Singh, K.K. and Shukla, B.D. 1995. Abrasive peeling of potatoes. *J. Fd. Engg.* 26: 431-442.

Singh, V., Verma, D.K., and Singh, G. 2013. Development of pineapple peeler-cum-slicer. *Pop. Kheti,* 1(2): 21-24.

Siti Mazlina, M.K., Nur Aliaa, A.R., Nor Hidayati, H., and Intan Shaidatul Shima, M.S. 2010. Design and development of an apparatus for grating and peeling fruits and vegetables. *Am. J. Fd. Technol.* 5(6): 385-393.

Sommer, F. 1997. Device for peeling elongated vegetables. United States Patent No. 5669293. Available: http://www.freepatentsonline.com/5669293.html

Thompson, V.L. and Harrell, T.T. 2003. Pumpkin cutting apparatus. United States Patent No. 6655032B2. Available: http://www.freepatentsonline.com/6655032.html

Thongsroy, B. and Klajring, V. 2015. Development of fruit peeling machine using a two-way blade. *The 16th TSAE national conference and the 8th TSAE international conference.* 53-56.

Ukatu, A.C. 2005. Development of an industrial yam peeler. *Agric. Mechanization Asia Africa Latin Am.* 36 (2): 21-27.

Ullah, M.A., and Haque, M.A. 2008. Studies on fruiting, bearing habit and fruit growth of jackfruit germplasm. *Bangladesh J. Agric. Res.* 33 (3): 391-397.

Visvanathan, R., Sreenarayanan, V.V., and Swaminathan, K.R. 1996. Effect of knife angle and velocity on the energy required to cut cassava tubers. *J. Agric. Engg. Res.* 64: 99-102.

Appendices

APPENDIX A

ANOVA for the factors of peeling operation of developed machine

Table A.1 ANOVA for time of peeling

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	554.454	277.227	130.2302	0.0000
S	2	1455.620	727.810	341.8964	0.0000
LS	4	15.664	3.916	1.8395	0.1652
Error	18	38.317	2.129		

Coefficient of variation: 4.21%

Coefficient of deviation for comparing L/R means: 1.444 (significant)

Coefficient of deviation for comparing L within R means: Not significant

Table A.2 ANOVA for peeling efficiency

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	105.698	52.849	75.6800	0.0000
S	2	480.292	240.146	343.8884	0.0000
LS	4	7.195	1.799	2.5757	0.0728
Error	18	12.570	0.698		

Coefficient of variation: 1.07%

Coefficient of deviation for comparing L/R means: 0.8273 (significant)

Coefficient of deviation for comparing L within R means: Not significant

Table A.3 ANOVA for bulb wastage (%)

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	42.752	21.376	92.5971	0.0000
S	2	341.213	170.607	739.0304	0.0000
LS	4	8.185	2.046	8.8637	0.0004
Error	18	4.155	0.231		

Coefficient of variation: 4.52%

Coefficient of deviation for comparing L/R means: 0.4757 (Significant)

Coefficient of deviation for comparing L within R means: 0.823 (Significant)

APPENDIX B

ANOVA for the factors of cutting, coring operation of developed machine

Table B.1 ANOVA for time of cutting-coring

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	225.275	112.637	125.1737	0.0000
C	2	270.229	135.115	150.1526	0.0000
LC	4	4.096	1.024	1.1380	0.3703
Error	18	16.197	0.900		

Coefficient of variation: 4.27%

Coefficient of deviation for comparing L/R means: 0.9390 (significant)

Coefficient of deviation for comparing L within R means: Not significant

Table B.2 ANOVA for coring efficiency

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	236.308	118.154	48.2111	0.0000
C	2	181.225	90.612	36.9731	0.0000
LC	4	10.487	2.622	1.0697	0.4002
Error	18	44.114	2.451		

Coefficient of variation: 1.99%

Coefficient of deviation for comparing L/R means: 1.5496 (significant)

Coefficient of deviation for comparing L within R means: Not significant

Table B.3 ANOVA for bulb wastage

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
L	2	82.032	41.016	45.9251	0.0000
S	2	74.220	37.110	41.5517	0.0000
LS	4	0.296	0.074	0.0828	
Error	18	16.076	0.893		

Coefficient of variation: 10.01%

Coefficient of deviation for comparing L/R means: 0.9354 (Significant)

Coefficient of deviation for comparing L within R means: Not significant

APPENDIX C

Comparison of developed jackfruit peeler cum core machine with the manual operation

A. Manual operation

Fruit no.	Weight of jackfruit, kg	Time of cutting, min	Time of bulb separation, min	Cumulative time of operation, min	Weight of bulb (without seed), kg	Cumulative weight of bulb, kg
1	8.12	7.55	21.21	28.76	2.13	2.13
2	7.50	6.52	17.37	52.65	1.51	3.64
3	10.05	8.90	23.50	85.05	2.44	6.08
4	9.50	8.75	22.43	116.23	2.67	8.75
5	8.45	7.84	22.38	146.45	2.18	10.93
6	7.80	7.50	19.12	**173.07**	1.67	**12.6**

A.1 Capacity calculation (kg/h)

Total weight of jackfruit = 51.42 ~ 50 kg

Total time of operation = 173.07 min = 2.88 h

$$\text{Throughput (kg/h)} = \frac{(\text{Total weight of jackfruit})}{(\text{Processing time})}$$

$$= \frac{(50)}{(2.88)}$$

$$= 17.36 \text{ kg/h}$$

A.2 Time required per fruit (min/fruit)

$$= \frac{(2.88 \times 60)}{(6)}$$

$$= 28.8 \text{ min/fruit}$$

A.3 Cost analysis of manual operation

A.3.1 Assumption

1. Number of workers required = 1
2. Working hours per day = 8h
3. Wages of worker (1person) per day of 8hours = Rs. 350 /-
4. Cost of coconut oil per kilogram = Rs. 70 /-
5. Coconut oil required per hour = 60 ml

A.3.2 Cost of manual operation per hour

(i) Wages of worker per hour (A) = 350÷ 8

= Rs. 43.75 /-

(ii) Cost of coconut oil (B) = 60 × 70 / 1000

= Rs. 4.2 /-

Total cost of operation per hour = (A + B)

= (43.75 + 4.2)

= Rs. 47.5 /-

A.4 Benefit-cost ratio

A.4.1 Assumptions

1. Cost of raw jackfruit per kilogram = Rs. 10 /-
2. Manual working hours per day = 8 h
3. Manual working days per year = 120 days
4. Selling price of processed bulbs per kilogram = Rs.120 /-

A.5.2 Actual performance

1. Cost of manual operation per hour = Rs. 47.5 /-

2. Actual capacity of worker = 17.36 kg/h

3. Bulb obtained from 51.42 kg of jackfruit = 12.6 kg

A.5.3 Calculation

1. Cost of raw jackfruit per year = $10 \times 120 \times 17.36 \times 8$

   = Rs. 166656 /-

2. Actual cost of manual operation per year = $47.5 \times 8 \times 120$

   =Rs. 45600 /-

3. Weight of jackfruit processed per year = $17.36 \times 8 \times 120$

   = 16665.6 kg

4. Total weight of bulb obtained per year = 4083.75 kg

5. Total Cost of obtained bulb per year (gross income) = Rs. 490050 /-

6. Net income = (Total gross income – Actual processing cost)

   = 490050 - 45600

   = Rs. 444450 /-

Benefit-cost ratio $= \frac{(444450)}{(166656)}$

= **2.66:1**

B. Mechanical operation

Fruit no.	Weight of jackfruit, kg	Time of peeling and coring -cutting, min	Time of bulb separation, min	Cumulative time of operation, min	Weight of bulb, kg	Cumulative weight of bulb, kg
1	8.29	3.25	9.35	12.6	1.94	1.94
2	10.50	3.6	12.50	28.7	2.30	4.24
3	8.63	3.41	9.89	42	1.81	6.04
4	7.23	2.76	8.35	53.11	1.30	7.34
5	9.19	3.35	11.75	68.21	1.72	9.06
6	8.15	3.06	8.78	**80.05**	1.57	**10.63**

B. Capacity calculation (kg/h)

Total weight of jackfruit = 51.85 ~ 50 kg

Total time of operation = 80.05 min = 1.33 h

$$\text{Throughput (kg/h)} = \frac{(\text{Total weight of jackfruit})}{(\text{Processing time})}$$

$$= \frac{(50)}{(1.33)}$$

= 37.59 kg/h

B.2 Time required per fruit (min/fruit)

$$= \frac{(1.33 \times 60)}{(6)}$$

= 13.3 min/fruit

B.3 Number of jackfruit processed per hour

$$= \frac{(6)}{(1.33)}$$

$$= 4.51 \sim 5 \text{ fruit/h}$$

B.4 Cost analysis of mechanical operation

B.4.1 Fabrication cost of the machine including the cost of material (C)

1) Frame assembly = Rs. 9050/-
2) Fruit holder assembly = Rs. 4500/-
3) Corer assembly = Rs. 8400/-
4) Peeler assembly = Rs. 4900/-
5) Idler pulley arrangements = Rs. 2100/-
6) Power transmission unit = Rs. 16000/-
7) Miscellaneous works = Rs. 2000/-

Therefore, C = (9050+4500+ 8400+4900+2100+16000+2000)

= Rs. 46950/-

B.4.2 Assumptions

1) Expected life years (L) = 10 years
2) Salvage value @ 10 % of machine cost (S) = Rs. 4695/-
3) Rate of interest per year (i) = 12%
4) Number of workers required = 1
5) Wages of worker (1person) per day of 8 hours = Rs. 300 /-
6) Working days per year = 120 days
7) Working hours per day = 8 h
8) Annual use (H) (expected operational hours) = 960 h
9) Repair and maintenance cost = 5% of machine cost
10) Insurance and shelter = 1.5% of machine cost
11) Energy cost per kWh = Rs. 6.50 /-

173791

12) Cost of coconut oil per kilogram = Rs. 70 /-

13) Coconut oil required per hour = 60 ml

B.4.3 Fixed cost per hour

(i) Depreciation cost (D) per hour $= \frac{(C-S)}{(L \times H)}$

$$= \frac{(46950-4695)}{(10 \times 960)}$$

= Rs. 4.40/-

(ii) Interest (E)/hour $= \frac{(C+S)}{(2)} \times \frac{(i)}{(H)}$

$$= \frac{(46950+4695)}{(2)} \times \frac{(12)}{(100 \times 960)}$$

= Rs. 3.22/-

(iii) Insurance, shelter etc., (F)/hour $= \frac{(C)}{(H)} \times \frac{(i)}{(100)}$

$$= \frac{(46950)}{(960)} \times \frac{(1.5)}{(100)}$$

= Rs. 0.73/-

Total fixed cost per hour = (D + E + F)

= 4.40+3.22+0.73

= Rs. 8.35 /-

B.4.4 Variable cost per hour

(i) Wages of worker (G)/hour = 300÷ 8

= Rs. 37.5 /-

(ii) Repair and maintenance cost (H)/hour $= \frac{(C)}{(H)} \times \frac{(i)}{(100)}$

$$= \frac{(46950)}{(960)} \times \frac{(5)}{(100)}$$

=Rs. 2.44 /-

(iii) Energy consumption per jackfruit = 0.0149 (Table 4.10)

Number of jackfruit processed per hour = 5 fruit/h

Energy cost (I) per hour = 0.0149×5×6.5 = Rs. 0.4842/-

(iv) Cost of coconut oil (J) per hour = 60 × 70 / 1000

= Rs. 4.2 /-

Total variable cost per hour = (G+H+I+J)

= 37.5+2.44+0.4842+ 4.2

= Rs. 44.624 /-

Total operating cost of machine per hour = (Fixed cost +Variable cost)

= 8.35 + 44.624

= Rs. 52.97/-

B.5 Benefit-cost-ratio

B.5.1 Assumptions

1. Cost of raw jackfruit per kilogram = Rs.10/-
2. Machine working hours per day = 8 h
3. Machine working days per year = 120 days
4. Selling price of processed bulb per kilogram = Rs. 120/-

B.5.2 Actual performance of the machine

1. Operating cost of machine per hour = Rs. 52.97/-
2. Actual capacity of machine = 37.59 kg/h
3. Bulb obtained from 51.85 kg of jackfruit = 10.63 kg

B.5.3 Calculation

1. Cost of raw jackfruit per year = 10×120×8×37.59

   = Rs. 360864/-

2. Actual operating cost of machine per year = 52.97×8×120

   = Rs.50851.2/-

3. Weight of jackfruit processed per year = 37.59 ×8×120

   = 36086.4 kg

4. Total weight of bulb obtained per year = 7398.23 kg
5. Total cost of obtained bulb per year (gross income) = Rs. 887787.6/-
6. Net income = (Total gross income – Actual processing cost)

   = 887787.6 – 50851.2

   = Rs. 836936.4/-

$$\textbf{Benefit-cost ratio} = \frac{(836936.4)}{(360864.0)}$$

$$= \textbf{2.32:1}$$

Abstract

DEVELOPMENT AND EVALUATION OF A JACKFRUIT PEELER CUM CORER

by

HAREESHA T SHIDENUR

(2014-18-116)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Agricultural Processing and Food Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2016

ABSTRACT

India is the largest producer of jackfruit followed by Bangladesh and Thailand. Kerala, which lies in the southernmost part of Western Ghats, is well known for its diversity in jackfruit with cultivated area of 90,225 ha and production of 294 million fruits per year. Peeling, coring and bulb separation of jackfruit are time consuming, causes drudgery and very tedium in manual operation. However, a major chunk of the production is wasted due to lack of post-harvest technological interventions, and hence jackfruit is considered as underutilized fruit. The present study aims at development and evaluation of a jackfruit peeler cum corer machine. The principle operation of the machine is, as the jackfruit rotates peeling was done helically due to the linear motion of the blade from bottom to top. Similarly cutting-coring operation was performed by screw mechanism which pressed the core removing tool against the fruit and cut into four portion. Finally bulbs were separated manually.

Performance evaluation of the machine was conducted in the laboratory to optimize the speed of fruit holder (90, 120 and 150 rpm) and corer pulley (110, 130 and 150 rpm) with three size of jackfruit, by considering the minimum processing time and bulb wastage with higher efficiency. The peeling operation at optimized speed (90 rpm) showed minimum bulb wastage for small (7.85%), medium (7.24%) and large (6.20%) sized fruits with high peeling efficiency of 85.27, 83.51 and 80.64% with a trend of increasing operational time of 38.24, 44.58 and 50.34 sec respectively. Similarly coring operation at optimal speed (130 rpm) showed processing time of 16.98, 22.39 and 24.83 sec and high coring efficiency of 92.85, 90.32 and 82.03% with bulb wastage of 10.337, 7.81 and 6.09% respectively. The average power consumption of optimal operational speeds for medium size jackfruit with load was found as 0.0149±0.0029 kWh/fruit whereas in without load condition was found to be 0.0104±0.0007 kWh/fruit. As per the comparative study, the average time taken for peeling, cutting-coring and bulb separation was more (28.8 min/fruit)

during manual operation and in case of mechanical operation it was only 13.3 min/fruit. The maximum throughput of machine was 37.5 kg/h, whereas in manual operation 17.36 kg/h. The cost of the machine has been estimated as Rs. 46950/-. The operational cost of the machine was Rs. 52.97/h whereas, in manual operation, it was Rs. 47.5/h. The benefit-cost ratio of the developed machine was 2.32:1 and in case of manual operation, it was 2.66:1.