DESIGN, DEVELOPMENT AND TESTING OF A PEELER CUM CUTTER MACHINE FOR TENDER JACKFRUIT

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DESIGN, DEVELOPMENT AND TESTING OF A PEELER CUM CUTTER MACHINE FOR TENDER JACKFRUIT

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by

Sandeep Singh Rana

(Roll Number: 514FP1002)

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under the supervision of

Dr. Rama Chandra Pradhan

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This is to certify that the work presented in this dissertation entitled '*Design, development and testing of a peeler cum cutter machine for tender jackfruit'* by *Sandeep Singh Rana*, Roll Number 514FP1002, is a record of original research carried out by him under my supervision and guidance in partial fulfilment of the requirements of the degree of *Doctor of Philosophy* in *Food Process Engineering*. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Dr. Rama Chandra Pradhan
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Dedicated to my Father

Declaration of Originality

I, *Sandeep Singh Rana,* Roll Number *514FP1002* hereby declare that this dissertation entitled "*Design, development and testing of a peeler cum cutter machine for tender jackfruit"* represents my original work carried out as a research scholar of NIT, Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT, Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT, Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

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Abstract

Jackfruit (*Artocarpus heterophyllus*), is native to Southeast Asia. India is believed to be the land of Jackfruit and from centuries it has been play a significant role in Indian agriculture and culture. Jackfruit is widely distributed fruit crop in India. The young fruit is used as vegetable, which contain high amount of vitamins and minerals. Jackfruit is found to be a novel, highly nutritive and inexpensive edible fruit available in all parts of India including Odisha, Bihar and West Bengal. However, due to lack of proper processing technology the marketing and transportation of jackfruit is a challenge. Existing traditional practices results in higher cost of processing, because these are time consuming, labour intensive processes, low processing capacity. The physical and chemical properties of the product are helpful in planning and fabrication of equipment or structure for transportation, handling, processing, storing and even for value addition and quality control. The research was conducted on two varieties of tender jackfruit [hard (HV) and soft variety (SV)]. Based on maturity, the tender jackfruits were divided into four stages (i.e. Stage 1, 2, 3 and 4) and their physical, mechanical, chemical and textural properties were determined for both the varieties. Physical properties like weight, length, diameter, geometric mean and arithmetic mean diameter were increasing with the increase in size for both the varieties. There was a significant increase in TSS in both the varieties (HV: 1.5 ± 0.02 to 5.1 ± 0.03; SV: 2.7 ± 0.05 to 7.1 ± 0.05 ^{o}Brix) from stage 1 to 4 because of ripening of fruit (at level $p<0.05$ of significance). The hardness, fracturability and springiness increased with maturity but on the counterpart, there is a decrease in adhesiveness, cohesiveness, chewiness and gumminess. The nutritional properties and energy values were inevitably increased whereas vitamin content was decreased from stage 1 to 4 in both the varieties. Jackfruit peeling cum cutting machine was designed by using SolidWorks-2015 software and fabricated for tender jackfruit. It is capable of washing, peeling and cutting of tender jackfruit effectively. It can process all sizes of tender jackfruit with the effective throughput capacity of 25 kg/hr. All food contact parts of the machine are of Stainless Steel- Grade 304. The operating conditions such as forward speed of peeling arm, rotating speed of jackfruit and rotating speed of cutter were optimized for maximum efficiency of machine and minimum loss in processing of tender jackfruits. The processing activities like washing, sorting, peeling and cutting enhanced oxidative stress in fresh cut jackfruit during storage. Moreover, it also has the ill effects on quality of fresh-cut tender jackfruit with an increase in microbial contaminations, excessive tissue softening, and depletion of phytochemicals and browning during the storage. Hence, this study was conducted as a solution to the above problem. The synergistic effect of pre-treatment (i.e. blanching of peeled tender jackfruit slices in optimised conditions) with different storage conditions (i.e. room, refrigerated and freeze) with different packaging films (i.e. High density polyethylene, Low density polyethylene and Polypropylene) were determined. The packaging of jackfruit slices reportedly increase the shelf life of fresh-cut tender jackfruit slices. The modified atmospheric packaging was also used to increase the shelf life of fresh cut tender jackfruit slices. From the response variables, the best combination of independent variables resulted in 10% concentration of CO_2 and 20% concentration of O_2 for HDPE packaging film. At these conditions, the sample can be preserved for 15 days at 5±1°C and for 20 days at -18±1°C. However, during storage, changes in physicochemical properties of fresh cut tender jackfruit was related to change in its colour as well. Colorimeter measurements are best for the samples with homogeneous colour. However, for samples with non-homogenous colour or large size (like fruits and vegetables), the colorimeters are inappropriate and inaccurate.The aim for this study to quantify the amount of browning in fresh cut tender jackfruit slices by using image analysis technique and justified by comparing them with existing techniques like sensory examination, enzyme activity, and colorimeter. It can be concluded from the results that, rate of browning was rapid in fresh cut tender jackfruit slices in control and normally packed groups. Correlation co-efficient of 0.96, which showed that image analysis system is an accurate and highly consistent method to quantify the color of fruits and vegetables. The value for Return on investment (ROI) for the machine is 209.61%. Pay-back period of the investment is very less, i.e. 34 working days. Thus the fabricated machine can highly be considered due to lower operating cost with low breakeven point and very high return on investment. Cost of minimal processing and packaging of tender jackfruit slices is ₹3.46INR (0.05 US$) per kg.

Key-words: *SolidWorks; minimal processing; Image analysis; colorimeter; browning; tender jackfruit; Modified atmospheric temperature.*

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List of Symbols and Abbreviations

%	- Percentage
$\bar{X}$	- Arithmetic mean
σ_x	- Standard deviation
₹ (INR)	- Indian rupee
ANOVA	- Analysis of variance
BCR	- Benefit-Cost Ratio
BEP	- Break Even Point
CCD	- Central Composite Design
cfu	- Colony forming unit
cm	- Centimetre
D	- Diameter
d	- Diameter of shaft
Da	- Arithmetic diameter
df	- Degrees of freedom
Dg	- Geometrical diameter
Eq^n	- Equation
F_{max}	- maximum force of failure
f_s	- Maximum allowable shear stress
g	- Gram
H	- Height
h	- Hour
HDPE	- High-density polyethylene
hp	- Horse power
J	- Joule
kg	- Kilogram
kJ	- Kilojoule
L	- Length
M	- Meter
mc	- Moisture content
mg	- Milligram
min	- Minute
ml	- Millilitre

mm	- Millimetre
FAO	- Food and Agriculture Organization
N	- Normality/Newton
^{o}Brix	- Degree Brix
^{o}C	- Degree Celsius
ϕ	- Sphericity
PBP	- Pay-Back-Period
pH	- Potential of hydrogen
ppm	- Parts per million
r	- Inner radius
R	- Radius
R^2	- Regression co-efficient
RH	- Relative humidity
ROI	- Return-On-Investment
rpm	- Revolution per minute
RSM	- Response surface methodology
S	- Overall housing area
s	- Second
S_F	- Safety factor
T	- Torque on the shaft
TPA	- Textural Profile Analysis
TPC	- Total plate count
TSS	- Total soluble solids
UV-Vis	- Ultra violent-visible
w.b	- Wet basis
ΔE	- Total colour change
θ	- Angle of repose
π	- Pi

Chapter 1

Introduction

India recently became the world's second largest producer of fruits and vegetables with 12.6% of the total world production of fruits and 14% of the total world production of vegetables (Source: Ministry of Agriculture & Farmers Welfare, 2017). Fruits and vegetables are 90% of the total production of the horticultural crop in India Veeragavatham *et al.* (2004). At present India is among the largest producers of fruits and vegetables and is leading in several horticultural crops, such as mango, bananas, papaya, cashew-nut, areca nut, potatoes and okra. Accurate assessment of the production of fruits and vegetable is difficult because of cultivation practices. Vegetables are mostly cultivated in small fields or kitchen gardens hence it makes their assessment more difficult. Many agricultural plants have crops multiple harvesting at during harvesting season.

According to the Ministry of Agriculture & Farmers Welfare, India (2017) the estimated production of vegetables is 175 million tonnes, from an area of 10.3 million hectares during the year 2016-17. Among all the states, the leading vegetable producing states are Uttar Pradesh and West Bengal, which produced almost one-third of country's total production. Odisha stands 7th in the position with 5% of the country's production (Figure1.1).

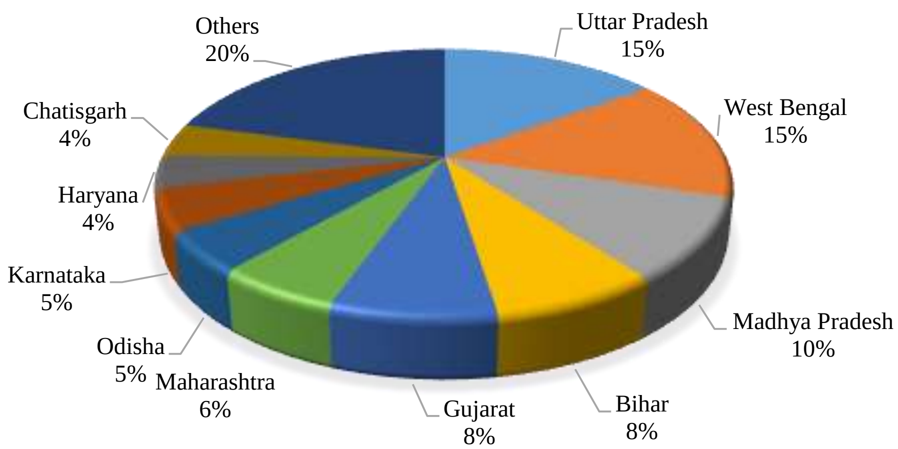

Figure 1. 1: State wise production of vegetables in India during 2016-17

Source: Ministry of Agriculture & Farmers Welfare. (2017).

According to the National Horticulture Board (2014), only 76% of vegetables are consumed as fresh and 20-22% are accounted for losses and wastage. The processing and value addition of fruits and vegetables in India is very less, that is around 2-4% of total production, which is in contrast to the extent of processing of fruits in several other developing countries such as Malaysia (83%), Philippines (78%) and Brazil (70%).

1.1 Fruits and vegetables

Fruits and vegetables have gained the widespread popularity among nutritionists, food processors, engineers and doctors in recent years. The reason for this sudden interest because of increased awareness on functional and nutritional values. The fruits and vegetables are the main source of vitamins, minerals and a major source of fibres. There are various other functional benefits found the consumption of fruits and vegetables. Hence, fruits and vegetables are delicious sources of essential nutrients and therefore, is one of the most desirable components of our diet.

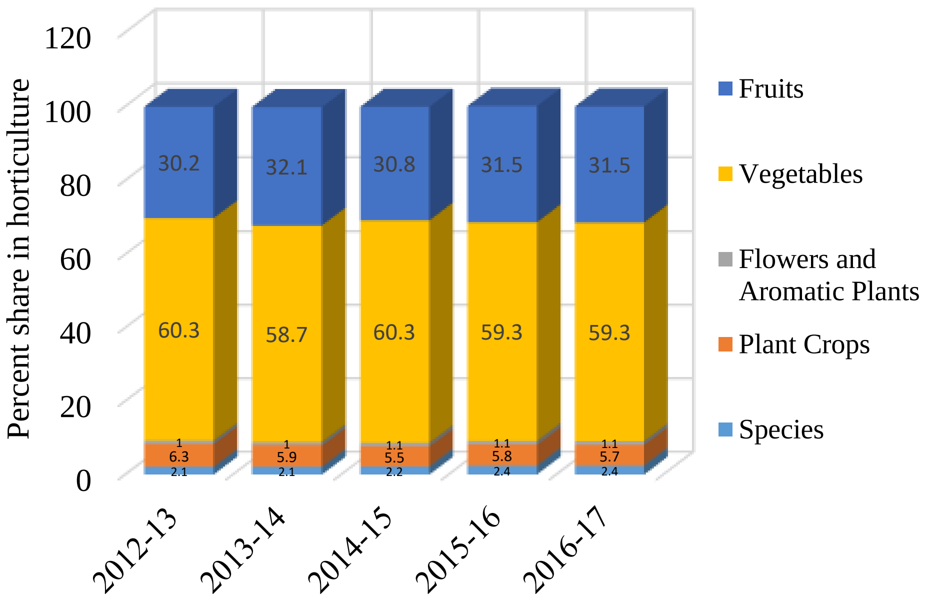

Figure 1. 2: Production share of various horticulture crops in India

Source: Ministry of Agriculture & Farmers Welfare. (2017).

Besides the health benefit, the increased production of vegetables also boosts the country's economy as this is an excellent source of income and employment. Production of vegetables remains the highest among horticultural crops during the last few years (Figure 1.2)

1.2 Jackfruit

Jackfruit *(Artocarpus heterophyllus)* believed to be originated from the southwestern rain forests of India. It is also cultivated in Bangladesh, Nepal, Sri Lanka, Malaysia and Indonesia. India is the 2nd largest producer of jackfruit (Area 1,02,000 ha production 14,36,000 t and productivity 11.4 t/ha). In India, it has a wide distribution in Assam, Tripura, Bihar, Uttar Pradesh, Odisha, the foothills of the Himalayas and the South Indian States. Popularly known as poor man's fruit in the eastern and southern parts of India.

Figure 1. 3: Jackfruits on the tree, ripened and tender form

Jackfruit is a horticultural crop, which is consumed as fruit and vegetable as well in both forms, i.e. mature and immature. In both, the forms jackfruit (Figure 1.3) is having various uses, which are providing food, fuel, fodder, timber as well as various medicinal and industrial products. Jackfruit considerably is not an invasive species. Hence, it is intensively grown as cultivation in most of the areas of the world mainly as a multipurpose plant in home gardens. But jackfruit has exceptional socioeconomic importance in South Asian countries; especially in India, China, Pakistan, Indonesia and Bangladesh. With multiple benefits Jackfruit is considered the National fruit of Bangladesh. It is reported that every part of the treehas medicinal properties. It has wide distribution all over India and mostly grown as shade crop in the coffee plantation (Ghosh and Venkatachalapathy, 2014). Since jackfruit is an underutilised horticultural crop; thereare no proper statistical data on its production. The area and production of jackfruit for last three years are shownin Figure 1.4.

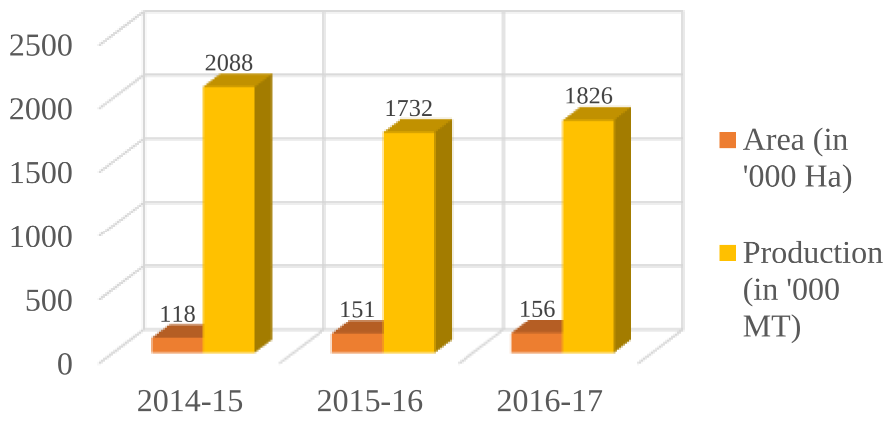

Figure 1. 4: Area and production of Jackfruit for three years
Source: Ministry of Agriculture & Farmers Welfare. (2017).

1.3 Agronomy of jackfruit tree and fruit

Jackfruit is the biggest tree-borne natural product on the planet weighing up to 40 kg (Singh, 1986). It is known for its large size and irregular shape (mostly oval). It has a thick peel with sharp hexagonal spines. The fruit can be as large as 90 cm in length and 50 cm in diameter. According to Veeragavatham *et al.*, (2004) the weight of fruit ranges from 2-40 kg. The average yield ranges from 20-200 jackfruits per tree. The ripe jackfruit has a very low shelf life in ambient conditions and it changes its colour to brown during deterioration. Although ripe fruit can be stored up to 6 weeks in cold storage at temperature ranges from 11±1°C and relative humidity 90±5%. The pulp of the ripe fruit is good source of carbohydrates, proteins, energy and vitamin A. The pulp yield from fruit ranges between 25-40%, this pulp can be consumed directly as fresh or can be stored as syrup. The unripe fruit is very similar to the breadfruit and often consumed and cooked as a vegetable (Jaiswal and Amin, 1992).

Differentvariety of jackfruit has a different bearing age. For instance, Singapore variety of jackfruit has an early bearing variety, which can bear fruit in 2-3 years. There are many early bearing varieties of jackfruit available in India and Sri Lanka as well. Whereas in general most of the varieties bear the fruits in 4-6 years after transplantation. According to Azad *et. al.*, (1999), Bangladesh has developed tissue cultured propagated plants which can bear fruits in less than 3 years. There are some varieties, which are well known for their late bearing of fruits. However, it may take 8-10 years for vegetative propagation of tree and bear the fruits after transplanting.

There are also regional aspects like soil and climate, which affect the fruit bearing age of jackfruit tree. In south India, the average fruiting age of the tree is 5-6 years but in north India, the fruiting delays because of cold climate at altitudes. Climatic conditions may also affect the production from a tree by affecting the number of fruits per tree and the weight of fruit. In favourable conditions, the fruits are heavier and there are more,number of fruit per tree (Ghosh, 1996).

1.4 Importance of Jackfruit

Not only the fruit but every part of Jackfruit tree is traditionally used in Yunani and Ayurveda medicines (Gupta and Tandon 1996; Saxena and Bawa, 2009). According to the Ayurveda it can cure diseases related to kapha, pitha and also good for skin and it improve the glow to skin. Jackfruit is a very rich source of potassium and hence can serve an important role in diet of patients suffering from hypertension.

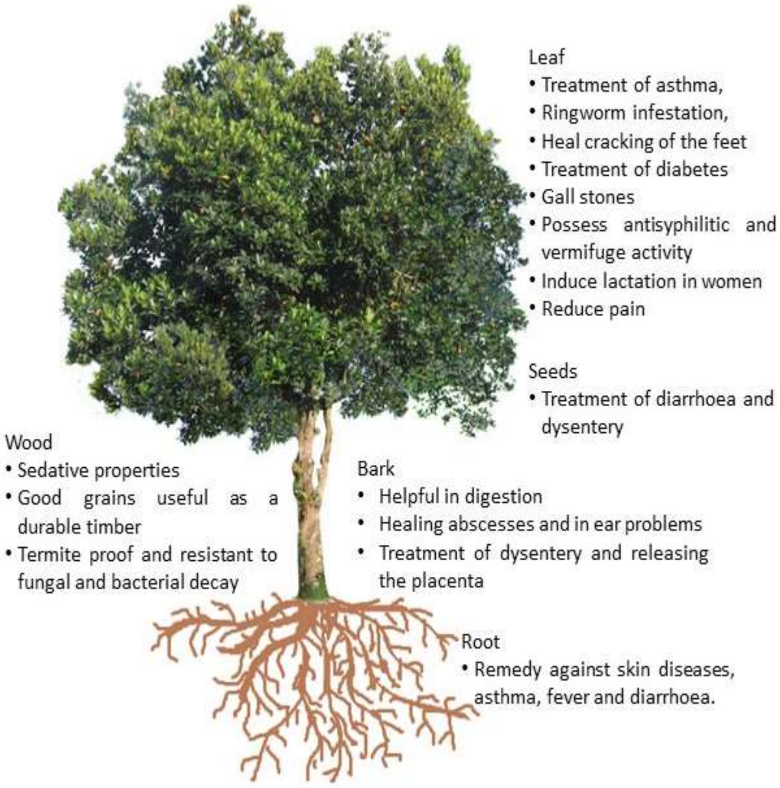

Figure 1.5: Medicinal and pharmaceutical advantages from each part of jackfruit tree

(Anonymous, 2006) It is found that ripe jackfruit is good for developing flesh, for preventing the formation of bile and for increasing the strength of body, phlegm and also for increasing virility. Various medicinal and pharmaceutical advantages from each part of jackfruit tree are briefed in Figure 1.5. The chemical and nutritional composition of jackfruit are presented in Table 1.1.

Commercial cultivation of jackfruit is still at a primitive stage in India, primarily because of the difficulty in procuring elite planting materials. In India, the major area under jackfruit is in Kerala state and it was regarded as heavenly fruit in the ancient periods. It is grown in an area of 97,536 ha with annual production of 348 million fruits and productivity of 3,568 fruits per ha. The state-wise value output from jackfruit in India is shown in Figure 1.6.

Table 1.1: Chemical and nutritional composition of jackfruit (100 g edible portion), fresh weight basis

Nutrients	**Tender fruit**	**Ripe fruit**	**Seed**
Water (g)	76.2-85.2	72.0-94.0	51.0-64.5
Protein (g)	2.0-2.6	1.2-1.9	6.6-7.04
Fat (g)	0.1-0.6	0.1-0.4	0.40-0.43
Carbohydrate (g)	9.4-11.5	16.0-25.4	25.8-38.4
Fiber (g)	2.6-3.6	1.0-1.5	1.0-1.5
Total sugar (g)	NA*	20.6	NA*
Total mineral (g)	0.9	0.8-0.9	0.9-1.2
Calcium (mg)	30.0-73.2	20.0-37.0	50.0
Phosphorus (mg)	20.0-57.2	38.0-41.0	38.0-97.0
Potassium (mg)	287.0-323.0	191.0-407.0	246.0
Sodium (mg)	3.0-35.0	2.0-41.0	63.2
Vitamin A (IU)	30.0	175.0-540.0	10.0-17.0
Vitamin C (mg)	12.0-14.0	7.0-10.0	11.0
Energy (kJ)	50-210	88-410	133-139

Sources: Gunasena et al.,1996; Azad, 2000.
NA = Information not available*

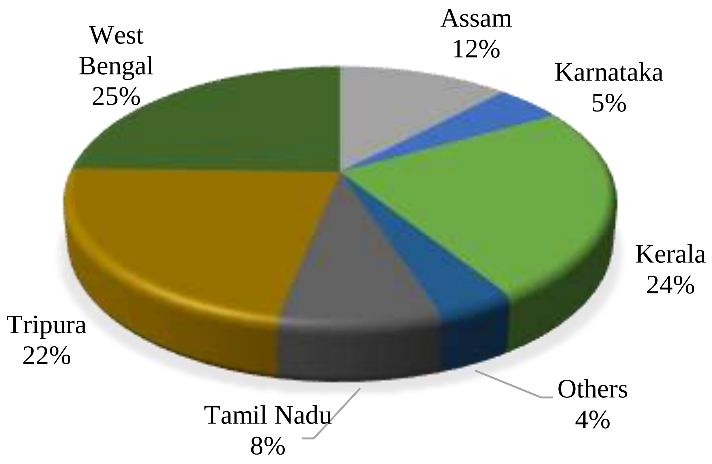

Figure 1. 6:State-wise value of output of jackfruit

(Country total ₹187270 lakhs, 2015-16)
Source: Statewide estimates of output from Agriculture & Allied Activities, CSO, M/o Statistics & Programme Implementation

1.5 Post-harvest processing

For the processing of jackfruit various unit operations such as harvesting, cleaning and washing, sorting and grading, storing, peeling, cutting and value addition are done. Washing in water before cutting or peeling is helpful to avoid contamination because there are always chance for harmful micro-organisms like bacteria to grow on the surface. So, before cutting the large sized fruits and vegetables (like jackfruit, breadfruit and pineapple), they must be scrubbed under running water with a brush. This practise will clean the unwanted parasites, soil, bacteria or any other kind of contamination on surface. U.S. Department of Agriculture, (2006) had concluded that using detergent while washing of horticultural crops cleans better than just running water but chemicals from soap or detergent might remain on the surface which may be harmful on later stages. The residue of chlorine in chlorine water for processing of horticultural crop is harmful, cited by FDA (2005).

Grading of jackfruitis done based on the size and the other most popular grading system for jackfruit is based on the maturity of the fruit (Sidhu, 2012). The fruits with a uniform shape, proper size and colour are selected for international marketing or special markets, while extra large and small fruits with non-uniform shapes and colour were sold locally. Peeling of tender jackfruit is a manual operationdone with help of choppers, knives or blades and oil is applied before cutting to avoid stickiness caused because of latex gum. Slicing or cutting is done by using a knife or by electric slicing machines.

To prevent any change in colour and to ease the processing of fruit and vegetables, blanching is carried out in hot water or chemicals. Blanching also helps to avoid the surface contamination of fruits during processing. In hot water blanching the product was dipped completely in boiling water. According to Fellows, (1997) the use of 1% sodium bicarbonate in the water used for blanching is very effective in preventing the bright green colour of vegetables and the texture can be protected using 2% calcium chloride solution. There are other types of blanching practices such as steam blanching. It takes a longer time for blanching and it costlier as well, but the nutrientloss is minimal in steam blanching. Blanching time for various vegetables is presented in Table 1.2.

Table 1. 2: Blanching times for vegetables

Food	Blanching time (minutes) using	
	Steam	Water
Leafy vegetables	2 - 2.5	1.5
Sliced beans	2 - 2.5	1.5 - 2
Squashes	2.5	1.5 - 2
Cabbage	2.5	2
Peas	3	3.5
Carrots	3 - 3.5	3 - 4
Cauliflower	4 - 5	5 - 6
Jackfruit bulbs	4 - 5	6 - 7
Potatoes	6 - 8	8 - 12

(Source: *Fellows, 1997*)

1.6 Storage and preservation

According to Shanmugam *et al.,* (1992) canning is mostcommonlypractised method to increase the availability of fruits and vegetables. Jackfruit in both formi.e. in tender and ripe forms can be canned and later it could be used in curries or as a table fruit (Berry and Kalra, 1987). Lal *et al.*, (1960) optimised the technique of canning tender jackfruit in brine solution containing 0.5-0.75% citric acid. According to Bhatia *et al.,* (1956) storing of caned jackfruits retain colour, taste and aroma for 19 weeks and later it started deteriorating.

Dehydrated flakes and flour from tender jackfruit is also a general practice for preservation of jackfruit, later which can be used to prepare pancake for breakfast. Vista Company in Sri Lanka uses the dehydrated jackfruit flakes as a vegetable. The jackfruit powder produced by Hardikars Food Processing, Pune (India) is used as a raw material for several products (Swami *et al*., 2014).

Packaging of fruits and vegetables is a proved technique forpreservation and storage of fresh-cut fruits and vegetables. The most common packaging technique used for the preservation of fruits and vegetables are modified atmospheric packaging(MAP) and controlled atmospheric packaging (CAP). Modified atmospheric packaging is the emerging technology in processing industries that reduce the spoilage of the product and increases its shelf life. Thiscan be done by altering the atmosphere inside the packaging. The important gases in modified atmospheric packaging are oxygen, carbon dioxide, nitrogen and other trace gases. Oxygen content inside the packaging should be minimal to control the respiration rate of the product. Higher respiration rates result in the ageingi.e.over-ripening of the respected fruit/ vegetable.

Along with the gases, packaging also plays an important role in extending the shelf life through controlling the respiration rate. Respiring and non-respiring are the two most important products of modified atmospheric packaging. Fruits and vegetables are the examples of respiring products. Respiring products of MAP require low permeability (ability to allow the gases to pass through it) and high barrier (restricting the passage of gases) packaging films. Meat and dairy products are the examples of non-respiring products. They require low permeability and high barrier packaging films.

Controlled atmospheric packaging (CAP) is another emerging technology in the packaging sector in competition to the modified atmospheric packaging. The major difference between these techniques is, in MAP there is no control over the process once the packaging is done but in CAP there is control over the process at different steps even after the packaging is done. In CAP the gas composition is kept constant either by adding or removing the constituting gases. Hence the natural deterioration/ spoiling is slowed down and the initial freshness of the product remains. The composition of gases changes with the factors such as type of product, packaging material and its permeability results and temperature at which the product is stored. If the temperature is low the micro-organisms growth will be low and preserves the quality of the product.

1.7 Value Added Products

According to Prakash *et al.*, (2009) tender jackfruits are used in curries and pickles as vegetables and ripe fruits are popularly used to make icecream, drinks, jam, halwa and jelly. In off season the desiccated pulp is used as dried fruit. Elevitch and Manner, (2006) has found the method to preparation of alcoholic beverage from the fruit. The payasam, a dish on special occasions, are prepared using dry fruits, milk and jackfruit bulbs. There are other various value-added products from tender and riped jackfruit which is available in market. There are some other products from jackfruit which are locally famous and only available in local markets. Some of the common and important value-added product from jackfruit is listed below in Table 1.3 and shown in Figure 1.7.

(a) (b) (c)

(d) (e) (f)

Figure 1. 7: Value-added products (a) Roasted Jackfruit seeds; (b) Young Jackfruit bulbs; (c) Unseasoned jackfruit; (d) Jackfruit wine (e) Jackfruit pickels (g) Jackfruit chips

Table 1.3: Some Value-added products from jackfruit

SL No	Product	Processing technique	Conditions of storage	Duration	Reference
1.	Ready to eat fresh jackfruit bulbs	Vacuum preserved (760mm lbs)	Refrigeration	15 days	Ukkuru and Pandey, (2005)
2.	Ready to serve jackfruit beverage	10% juice, 10-12% TSS, 0.3% acidity	-	-	Chopra and Chauhan, (2001); Singh *et al.,(*2001)
3.	Jackfruit squash	Fortification with Vitamin- C and ascorbic acid	24-30^{0}C	60 weeks	Bhatia *et al,(*1956)
			Room temperature	1 year	Sadaswam and Neelkantam, (1976)
4.	Jackfruit nectar	15-20^{0}Brix	Refrigeration	Few Days	CFTRI, (1977)
5.	Wine	Standardized wine making process	-	-	Krishnaveni *et al.*, (2000)
6.	Bulbs	Canned Jackfruit	Room temperature	19 weeks	Bhatia *et al.*,(1956)
			37^{0}C	6 months	Siddappa and Bhatia, (1956)
7.	Dehydrated jackfruit flakes	Drying	-	1 year	KAU, (1999)
8.	Jackfruit bar	Standardized method	Modified Polypropylene packets (MPP)	6 months	Krishnaveni *et al.*, (1999)
9.	Jackfruit pickles	Standard method	Glass jar	Up-to 1 year	CFTRI, (1977)
10.	Jackfruit chips	Fried + antioxidant (BHT and Sorbic acid)	MAP	3 months	Gokul brand kundapur
11.	Seed flour biscuits	Baking at standard method	LDPE/PLDPE; 24-30^{o}C	2 months	Ukkuru and Pandey, (2005)
12.	Roasted nuts	Roasting at high temperature	24-30^{o}C	Few Days	Bhatia *et al.*, (1956); Berry and Khan, (1957)

1.8 Organization of the Thesis

An overlook and concept of the flow of work that has been carried out to complete the research have been briefed as below:

Chapter 1 deals with the generalized introduction of fruits and vegetables. The uses and importance of fruit and vegetables. The status of India in processing and production of fruit and vegetables was also discussed. Besides this, the introduction and importance of tender jackfruit was included in this chapter. The various uses, importance, benefits, processing techniques and products available in market was discussed in details. This provides a summarized overview of the foundations for this research.

Chapter 2 includes the literature studied and reviewed during this work. The chapter includes the detailed review of every possible available literature on processing of tender jackfruit. Which helped to find the research gap and loop holes in processing of tender jackfruit. Finally, this helped to frame the objectives for the research which is discussed in the section.

Chapter 3 deals with the methodology followed to systematically achieve the framed objectives. The details of material required and methods followed to carry the experiment are discussed in brief. This also includes the concepts and procedure used to solve the problems arrives during the research.

Chapter 4 includes the results of the experiments performed. The findings and outcomes from each and every objective is discussed in details and every phenomenon is possible is justified with available literature and reasons. This chapter includes the scientific justification of research work and cost estimation of each process to justify the research economically as well.

Chapter 5 summarizes the significant findings of the work performed; and outlines the current limitations raised by the findings. Recommendations are provided for future work that would further enhance quality of design to be adopted by jackfruit industries.

After summary and conclusion, the Bibliography or list of references. It has a complete listing of all cited resources used to create your document. Reference lists are formatted according to the instructions provided by the most recent edition. At the end appendices are provided as an information that is not essential to explain the findings, but that supports analysis, validates conclusions or pursues a related point.

Chapter 2

Review of literature

2.1 Jackfruit

Jackfruit belongs to the family *Moraceae* and is widely cultivated in India and Bangladesh (Rehaman *et. al.,* 1999). The jackfruit tree is a medium-size evergreen tropical tree with the height of 8.5 to 24.5 m (28 to 80 ft) (Figure 2.1). Most of the fruit grows on main and side branches of tree which ease the harvesting of fruit. The average weight of jackfruit ranges between 1.5 to 9 kg, but the size of largest fruit can be massive and its weight may exceed 40 kg. According to Madruga *et. al.,* (2014), there are two jackfruit varieties i.e. soft variety and the hard variety. Varieties are distinguished on the basis of characteristics of the fruit flesh i.e. hard variety is crunchier, drier and less sweet but fleshier whereas, soft variety is softer, moister and much sweeter with darker gold colour flesh.

Figure 2. 1: Jackfruit tree in NIT Rourkela

2.1.1 Cultivation of jackfruit

Jackfruit is grown as a promising fruit in many parts of world (Figure 2.2). Generally, it is grown in farmstead with minimum or no maintenance like fertilization or irrigation practices etc. Because of monoecious behaviour, jackfruit is cross pollinated crop. Hence, the quality of fruit from new tree will always inferior as per the mother tree but the tree will be good enough for fodder and timber purpose (Haq, 2006). Vegetative propagation was advised over seed propagation in case of jackfruit, when it was grown for fruit. The vegetative propagation is able to genetically similar tree to mother tree. Vegetative propagated plants grow shorter which helps in management and harvesting, but this also cause lesser timber from tree. Few vegetative propagation practices being adopted to jackfruit are stooling or mound layering, cutting, air layering, grafting and budding. In India, Softwood and epicotyl grafting methods are recommended (Haq, 2003).

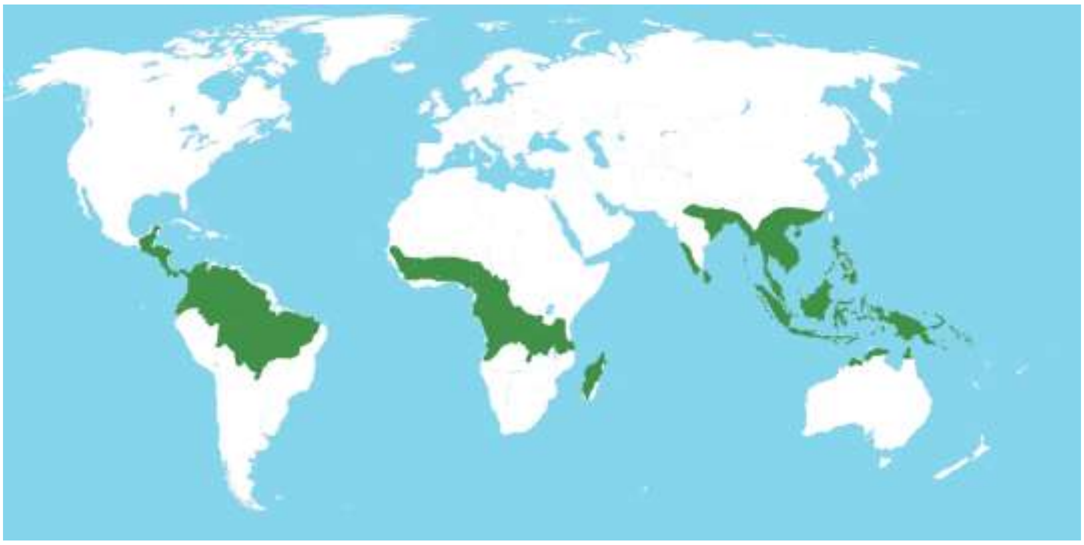

Figure 2.2**:** Spread of jackfruit in the world (Source: FAO report 2014)

The major problem in jackfruit cultivation is dropping of flowers and fruits. The basic reason behind this are off-season cultivation and water deficiency. The other reasons can be diseases, nutrition deficiency and insect or pest attack (Manna *et. al.*, 2006). Vegetable crops like brinjal, okra, chilli, tomato and pulses like gram, kalai, etc. are very likely to be grown around the jackfruit tree because it improves the soil quality and nitrogen content (Jamaludheen *et. al.*, 1997).

2.1.2 Fruiting

Fruits bearing age of jackfruit tree varies with variety, climate and management practises. There are early bearing varieties which bear fruit in 2-3 years and on the other side there are varieties which bear fruit in 6-7 years (Azad *et. al.*, 1999). The fully matured and well grown jackfruit tree can produce 200-250 fruits per season, with each weighing 5-35 kg, but with proper care and in favourable climatic conditions the weight of fruit can be up to 55 kg (Ghosh 1996) (Figure 2.3). According to Chaudhary and Khatri (1997), the yield of jackfruit varies because of differences such as plant age, locality, cultivars and season. But on a rough estimate average of 100-250 fruits per plant are harvested by most of the farmers.

A well grown jackfruit tree in favourable conditions can live for 100-120 years or even longer than that. Productivity is inversely proportional to the age of tree whereas timber cost is directly proportional to age of jackfruit tree (Medagoda and Tennkoon, 2001). The jackfruit tree yields fruits with maximum productivity after 12 years or more.

Figure 2.3: Tender and ripe jackfruit on tree (Location: NIT Rourkela)

2.1.3 Harvesting of jackfruit

Jackfruit are harvested as vegetable as well fruit hence the harvesting time varies. For vegetable purpose jackfruit is harvested on early stages of maturity. Jackfruit as vegetable is harvested in spring and in early summer. Seeds are soft in earlier stages and as the fruit matures the seed get harder and fruit matures in June, i.e. end of summer. Optimum maturity is considering after 90-110 days after the spikes appearance. The yield from tree depends on individual tree, season, locality, soil type, rainfall, temperature etc. (Elevitch and Manner, 2006). Harvesting is done by cutting the stalks attached with fruit. The indication of ripening of jackfruit are skin colour, spine, stalk turn yellow and hollow sound on tapping.

According to Acedo, (1992) the harvesting of jackfruit is advised to carry on after mid-morning and late afternoon. This will reduce the latex flow. The harvesting is carried on, depending on purpose of jackfruit (Karim *et. al.,* 2008). For example, for preparation of jackfruit pickle the fruit has to completely immature and harvested at very early stages. At this stage the bulbs and seeds are not yet formed. For the preparation of curries, the fully developed seeds and fruitlets are used. Partially mature and hollow sound, jackfruits are used for preparation of chips and various other curries. In metro and mega cities, the jackfruits are sold in small packages after cutting and peeling (Molla *et. al.,* 2008).

According to Valavi *et. al.,* (2011) Harvesting of jackfruit in tender or ripe form is equally difficult. The jumbo sized fruits are more likely to suffer injuries caused due to impact. Mechanical injuries during harvesting also leads to the deterioration of fruits on later stage. So during harvesting of jackfruit extra care was taken and it was done with the help of sack full of husk. The fruit was cut and separated from the branch and then it was thrown over the sack filled with husk to prevent mechanical injuries. Sometimes the fruit was lower with the help of rope to ground label and was collected by person on ground. One has to reach each and every fruit during harvesting and has to lower it properly, hence the harvesting of jackfruit is very tedious and laborious work.

After harvesting of Jackfruit (preferably in tender form) the fruits were left laid on field for a while, which facilitate to flow most of the latex from the fruit and it will ease the handling of fruit during storage or other operations. During flowing of latex special care was taken so that latex will not spread over the fruit because that will spoil the appearance of fruit and will affect the price of fruit in market (Mitra, 2010). During transportation of fruits from farm to market a layer of cushioning material was filled between the fruits. This cushioning material reduce the chances of mechanical damage and transportation injuries and also prevent the soiling of fruit from latex. The cushioning material can be leaves from banana tree or old newspaper or other material which was available in the farm and can fulfil the purpose (Acedo, 1992; Elevitch and Mariner, 2006).

2.1.4 Physiochemical properties of jackfruit

2.1.4.1 Total phenolic content

Total phenolic content of Jackfruit can be measured by taking the absorbance readings from UV spectrophotometer. If the juice contains large amount of phenols then it resembles the higher anti-oxidant content. The primary anti-oxidants in Jackfruit are polyphenols which gives the typical flavor and astringency to the fruit. Higher the presence of phenolic content, the absorbance of UV light will be higher. The total phenolic content of the juice is around 144-10086 mg GAE/L (Gallic Acid Equivalent per liter) and the anti-oxidant value i.e. DPPH (2,2-diphenyl-1-picrylhydrazyl) value is 10.37-67.46 (%) theoretically (Jagtap *et. al.*, 2010).

2.1.4.2 Fat and carbohydrate content

Jackfruit is rich in the carbohydrate content and low in protein and fat content. Jackfruit contains around 134 calories energy, 33 grams of carbohydrate content and <1 gram of protein and fat content. Fructose sugar takes the major part in the juice and accounts for 32 grams of total carbohydrate content. Due to the presence of large amount of sugars it results in the weight gain and dental problems (Soepadmo, 1992).

2.1.4.3 Vitamins, Minerals and other trace elements

Jackfruit are rich in the antioxidants such as DPPH and vitamins such as vitamin, B-complex vitamins such as folates, pyridoxine, pantothenic acid (vitamin B-5) and vitamin K. The nutritional composition of jackfruit is mentioned in Table 2.1.

Table 2. 1: Composition of jackfruit (100 g edible portion), fresh weight basis

Nutrients	Young fruit	Ripe fruit	Seed
Water (g)	76.2-85.2	72.0-94.0	51.0-64.5
Protein (g	2.0-2.6	1.2-1.9	6.6-7.04
Fat (g)	0.1-0.6	0.1-0.4	0.40-0.43
Carbohydrate (g)	9.4-11.5	16.0-25.4	25.8-38.4
Fibre (g)	2.6-3.6	1.0-1.5	1.0-1.5
Total sugars (g)	NA*	20.6	NA*
Total minerals (g)	0.9	0.8-0.9	0.9-1.2
Calcium (mg)	30.0-73.2	20.0-37.0	50.0
Magnesium (mg)	NA*	27.0	54.0
Phosphorus (mg)	20.0-57.2	38.0-41.0	38.0-97.0
Potassium (mg)	287.0-323.0	191.0-407.0	246.0
Sodium (mg)	3.0-35.0	2.0-41.0	63.2
Vitamin A (IU)	30.0	175.0-540.0	10.0-17.0
Vitamin C (mg)	12.0-14.0	7.0-10.0	11.0
Energy (kJ)	50-210	88-410	133-139

Sources: Arkroyd et. al., (1966); Soepadmo (1992); Gunasena et. al., (1996); Azad (2000).
NA = Information not available*

Minerals that are present in the Jackfruit are calcium, potassium, manganese, copper which are responsible for the balanced nutrition. 50% of the daily recommended vitamin C is provided by the Jackfruit solely. Presence of dietary fiber improves the resistivity power (Begum *et. al.,* 2014). Nearly 60% of whole jackfruit is considered as inedible (Subburan *et. al*., 1992), this include thick outer layer of rind, inner perigones and central core of fruit. It was generally considered as waste and this waste causes pollution. Researchers has been noticed this and found a noble way to utilize this waste. The jackfruit waste is proven as one of the best source of esterified pectin (Begum *et. al.*, 2014).

2.1.5 Functional components of jackfruit

According to Gupta and Tandon, (1996) and Saxena and Bawa, (2009) jackfruit was popularly used in medicines to cure kapha and pitha as mentioned in Ayurveda. It was also very useful to make many Yunani medical syrups to cure diseases. It was also believing in olden times that consumption of jackfruit was ideal to improve the glow of skin and helps in increase the sexual strength. These facts are also supported by many modern day researchers (Polak and Starmer, 2005; Wee *et. al.,* 2018).

Jackfruit is beneficious for both health and skin (Sonawame and Katti, 2016). It is associated with large amounts of anti-oxidants compared to the other fruits. Daily consumption of jackfruit helps in treating ulcers in the stomach, results in healthy skin, maintains blood pressure, and reduces the risk of cancer due to its anti-carcinogenic properties. Jackfruit is rich in vitamin A, C, E and B-complex and minerals such as calcium, phosphorous, potassium and iron (Jahan *et. al.,* 2011; Gupta *et. al.*, 2011).

The extract from seeds or bark of jackfruit tree are used to make medicines to helps digestion and treatment of diarrhoea and dysentery (Anonymous, 2006; Hossain and Nath, 2002). Whereas roots are used in making of medicines for skin diseases, fever etc. According to Gupta and Tandon, (2004), the ash of burnt bark of jackfruit tree is remedies to ear problems and leaves and latex are effectively used against asthma. Leaves are also used in medicines for pain relief.

2.1.5.1 Anti-diabetic

Scientists have studied the relationship between jackfruit and diabetes and found that diabetic patients who are given extracts of jackfruit have improved glucose tolerance as compared to those who are not given the extract. A recent study at Sydney University's Glycaemic Index Research Service has confirmed that consumption of unripe jackfruit can help fight high blood sugar level (Martin, 2016). It is also reported that an aqueous decoction of jackfruit leaf possesses hypoglycaemic effects in rats, mice and human health volunteers (Fernando *et. al.*, 1990, 1991).

The aqueous leaf extract is also known to inhibit α-amylase activity *in vitro* (Kotowaroo *et. al.,* 2006). Clinical study reports that the hot water extract of jackfruit leaves significantly improved the glucose tolerance in normal subjects and diabetic patients when investigated at oral doses equivalent to 20g/kg of starting material. Detailed analysis of three patents under this section reveals that besides the polysaccharides in the jackfruit leaves, other bioactive such as jacalin also contributes to the blood sugar reducing effect by this tree.

A Chinese patent claims the preparation of jackfruit leaf polysaccharide having molecular weight less than 100 kilo Dalton by a simple and cost-effective method that is beneficial for industrial production. The polysaccharide disclosed in the invention can be further used in the preparation of hypoglycaemic drugs and foods (Pan and Dang, 2017).

2.1.5.2 Anti-infection

The ethanolic and methanolic extracts of the jackfruit seed powder are studied for their effect on multidrug resistant methicillin resistant Staphylococcus aureus (Karthy *et. al.*, 2009). The search retrieved five patents listed in this section that claims the antibacterial, antiseptic, antimicrobial property of jackfruit plant and the corresponding phytochemicals. The γ-globulin preparation composed solely of simple IgG from jackfruit, can be safely applied to patients having selective immunoglobulin deficiency for the treatment of infection (Kondo and Kobayashi, 1990).

A Japanese patent claims an antibacterial agent and anantiseptic that contains greater than or equal to 200 ppm of the jack fruit (*Artocarpus heterophyllum Lam*) extract containing another lectin compound artocarpin as the bioactive (Kojima *et. al.,* 2004). The compound is obtained by extracting jackfruit seeds with water, or other organic solvents at normal temperature or under heating. Cosmetic products such as skin lotion, cream, or hair liquid can be prepared using the jackfruit extract containing the antibacterial agent (Suresh *et. al*., 1997).

Eisai Co Ltd. claimed new flavone derivatives from different species of *Artocarpus* and their use as antibacterial or antihypertensive agents (Uno *et. al*., 1991). Another Japanese patent claimed a useful antimicrobial agent containing one or more extracts from different plants including the leaves of *Artocarpus heterophyllus* for preserving food stuffs, cosmetics and quasi-drugs. The inhibition process increases the shelf life of extensive foodstuffs. It is highly safe and does not impair the quality of food stuffs (Oshima *et. al.*, 2000).

2.1.5.3 Anti-inflammatory

The leaves of *Artocarpus heterophyllus* also known as wood pineapple honey leaves are known for curing traumatic bleeding. A Chinese patent application claims a new use of jackfruit leaves for the preparation of medicines for treating oral ulcers (Chen, 2015). Anti-inflammatory property of bio-actives extracted from the jackfruit tree have also been claimed in two other Chinese patents by researchers from the University of Jiangxi. Traditional Chinese Medicine and Guilin Xing'an Anming Food Co., Ltd. respectively (Ren *et. al*., 2017a; Tang 2013a).

Another Chinese patent (Tang, 2013b) from discloses the method for extracting proteinase from jackfruit pericarp and use thereof as anti-tumor and anti-inflammatory medicine. The method is simple, stable, with less energy consumption, and produces stable proteinase at high recovery rate.

2.1.5.4 Anti-cancer

A Chinese patent discloses a method for preparing a medicament consisting of a mixture of two polyphenol compounds artoheterophyllin I and artoheterophyllin J extracted by ultra-sonication from jackfruit wood with 95% ethanol for inhibiting cancer cells of liver, lung and breast (Chung and Xu, 2015). Another Chinese patent claimed the extraction, separation and purification of vitexin xyloside from jackfruit (*Artocarpus heterophyllus lam*) leaves with high extraction efficiency. The extraction method is economical and suitable for industrial productions (Pan *et. al.,* 2017). Jackfruit leaf tissues are known to be rich in isopentenyl flavonoids and have anti-tumor activity making them potential candidates in the treatment of tumor diseases. (Yang and Jiang, 2018; Yang and Jiang, 2017a; Yang and Jiang, 2017b).

2.1.5.5 Other therapeutic applications

A Chinese patent claims the use of jackfruit extract for manufacturing medicines or food with anti-alcoholic function (Mei *et. al.,* 2010). Maoming Deweisheng Technology Co Ltd. has exploited the extraction of volatile aromatic components from jackfruit extracts and claimed the benefits of the fragrances and aroma in two Chinese patents. In one patent the inventors have claimed the use and method of alcoholic extraction of jackfruit for tobacco flavouring and reducing harmful substances when used in cigarettes (Shao and Xia, 2013). In another patent, the inventors have disclosed the method for extracting jackfruit aromatherapy oil using ionic liquid (Chen, 2014).

A Korean patent discloses a novel trimer 370 of flavan-3-ol which can inhibit glucosyltransferase (GTase) enzyme responsible for generating cavity-causing glucan with sugar substrate. The (-)-epiafzelechin-(4β→8)-afzelechin-(4α→8)-catechin compound extracted from jack fruit can completely inhibit (GTase) enzyme at 1.0mM concentration thereby having its application as a preventive medicine for dental caries (Ahn and Choi, 2000).

2.1.6 Uses of Jackfruit

Jackfruit tree is multi-purpose which provides food, fuel, fodder, timber and also used in many medicinal and industrial products. The major economical product from the tree is jackfruit, it is used in both tender and ripe forms. The tender jackfruit is readily used in making curries, pickles, chutney, pastes and other medicinal products (Prakash *et. al.,* 2009).

Elevitch and Manner, (2006) mentioned the modified procedure to prepare alcoholic liquor from fruit. Morton, (1987) used ripe bulbs to prepare concentrated jackfruit nectar and then made power from it. Samddar, (1985) mentioned that jackfruit seeds are edible and can be processed to improve the flavor and nutritional value of various products from jackfruit. Morton, (1987) also supported the nutritional aspect of jackfruit seeds and developed the innovative method to process them. Many attempts are made to develop the flour from jackfruit seeds (Anonymous, 1985; Mukprasirt and Sajjaanantakul, 2004a, b; Prakash *et. al.*, 2009; Tulyathan *et. al.*, 2002). Jackfruit seeds flour was found with high protein and carbohydrate. The tender leaves and flowers are also used in rural areas to make curries. Large seeds from fruits are eatable but not easily digestible. Jackfruit cotyledons are fairly rich in starch and protein (Singh *et. al*., 1991).

Table 2.2: Some reviews on different product from jackfruit

SL No	Product	Processing technique	Conditions of storage	Duration	Reference
1.	Freezed jackfruit bulbs	Freeze at -29^{o}C	Stored at -18^{o}C	-	Yi *et. al.,* (2016)
2.	Jackfruit candid product	Impregnated with cane sugar and glucose and subsequently drained and dried	Room temperature	Shelf stable	Ckkuru and Pandey, (2005)
3.	Jackfruit bulbs	Canning and preserved in brine solution (0.5-0.75% Citric acid)	-	-	Devi *et. al.,* (2014)
4.	Wine	Standardized wine making process	-	-	Krishnaveni *et. al*., (2000) Jagtap *et. al*., (2011)
5.	Vinegar	Riped fruits yielded 7% alcohol and 6% acetic acid	-	1 year	Datta and Bisioas, (1972)
6.	Dehydrated jackfruit flakes	Drying	-	1 year	KAU, (1999)
7.	Candid jackfruit	Osmo air dried; osmotic dehydration 30 min in 70^{o}Brix at 50^{o}C (20% glycerol for soft verities)	Ambient condition	-	Vazhacharicka *et. al.,* (2015)
8.	Jackfruit papad	Vacuum fried	Paper wrapping 20–30^{o}C	4-6 months	Kamath, (2008)
9.	Jackfruit jelly	Pulp extract: sugar: acid: Jelly = 1:1:0.6:0.8	-	-	Apsara and Pushpalatha, (2002)
10.	Seed flour biscuits	Baking at standard method	LDPE/PLDPE; 24-30^{o}C	2 months	Ukkuru and Pandey, (2005)

2.2 Processing of fruits and vegetables

There is very less literature available on processing and browning of tender jackfruit so in this section the review is done on available literature on jackfruit and as well as other fruits and vegetables. Fruits and vegetables are the parts of ovary of flowering plants which are also known as angiosperms. The coat of the fruit contains three layers. Inner layer called as endocarp which is in contact with the edible part of the fruit. Middle layer is called as mesocarp which acts as a separation between the pericarp and endocarp. Outer most layer is called as pericarp that acts as a protective layer to the fruits (Figure 4.4). Fruits contain high nutritious value with fiber, vitamins, and water contributing the major part of fruit (Thompson *et. al.,* 1974)

Fruits and vegetables contain the lower levels of fat, calories and sodium and zero cholesterol which helps in reducing the weight and other cardiovascular diseases. Fruits rich in the potassium content help in maintaining the blood pressure levels (Begum *et. al.,* 2014). Vitamin C is almost seen in every fruit and vegetable that keeps body tissues healthy and heals the wounds quickly. Dietary fiber is the non-digestible part that helps in relieving the constipation (Watada *et. al.,* 1990).

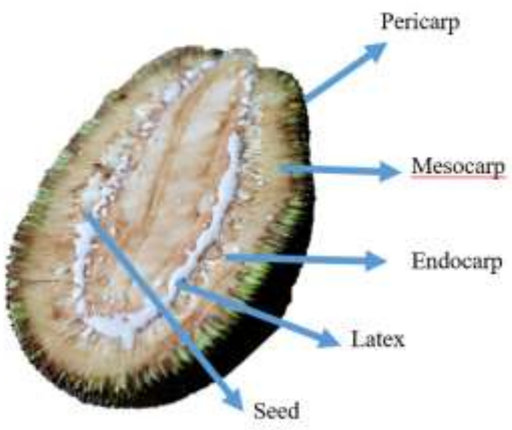

Figure 2.4: Different layers and parts of Jackfruit

They are also rich in folic acid which help in increase the red blood cells content. So pregnant women are advised to consume the fruits rich in folic acid for sufficient blood during delivery and proper fatal development (Watada *et. al.,* 1996). On the other hand, fruits rich in anti-oxidants such as polyphenols help in maintaining the body metabolism and fights against various types of cancer.

2.2.1 Minimal processing of fruit and vegetables

Minimal processing provides the ease of flexibility in utilising the food product. Hence this results in increase in the demand of the product in market. Minimally processed product are convenient and fresh, which pleases the end consumers and causes increase in sales (Watada *et. al.,* 1996). There are no or minimum use of preservatives or additives in fresh cut products, removing of peel and other inedible parts eliminate the extra cost of transportation and storage, it also felicitates in further processing of product and hence reduces the time for further processing, fresh cut product is more uniform and consistent in terms of quality (Garrett, 1998).

Although minimal processing of fruits and vegetables have many advantages, but there are some disadvantages as well. There will be physical damage to product during minimal processing of product. The peeling and cutting of fruits and vegetables causes changes like increase in metabolic reaction and respiration of product. These changes ultimately lead to the severe deterioration of the fruits and vegetables. (Cantwell, 1998; Saltveit, 1997; Varoquaux *et. al.,* 1990; Watada *et. al.,* 1990). There are some other physiochemical changes as well which can be caused by minimal processing. Colour change is one the most common and easily noticeable in early stage of deterioration. Along with decolourization of the product the changes like oxidization, polymerization, biosynthesis can also cause deterioration of product (Hyodo *et. al.,* 1978; López-Gálvez *et. al.*, 1996). Hanson and Havir, (1979) reported that oxidization of phenolic compound in presence of polyphenol oxidase or peroxidases causes the decolourization.

2.2.2 Browning of fruit and vegetables

The minimal processing of vegetables and fruits have acquired the swift vogue among consumers because of its nutritional benefits, fresh like nature and ease in use. The processes like washing, cleaning, sorting, grading, peeling, cutting and slicing are some examples of minimal processing. According to Sexena *et. al*., (2012) minimal processing of pre-cut fruit and vegetables effect the quality by increase the oxidative stress. Cause of degradation in quality are contaminations through microbes are increased, exhaustion of phytochemicals, tissue softening and browning.

Many citations are available to illustrate the advantages of numerous processing techniques to retain the quality of minimally processed fruits and vegetables (Raju and

Bawa, 2006; Albanese *et. al*., 2007; Koukounaras *et. al*., 2008). Storage of minimally processed fruits and vegetables at low temperature (4 to 6^{o}C) reported extension in their shelf life (Piga *et. al*., 2000). Browning, tissue softening and weight loss are major problems in storage of minimally processed products (Koukounaras *et. al*., 2008). The treatment of coating with sucrose, trehalose and NaCl on minimally processed apples reportedly solved those problems (Albanese *et. al*., 2007).

Use of anti-browning chemical such as ascorbic acid and citric acid prevent enzymatic browning in most of the seasonal vegetables and fruits (Limbo and Piergiovanni, 2006). Technique like irradiation assisted with dip treatment chemicals like potassium meta-bisulphite and citric acid were reported favourable in retention of quality in minimal processed potatoes (Baskaran *et. al*., 2007). According to Raju and Bawa, (2006) dip-treatment solo or in amalgamation with further techniques results advantageous in terms of maintaining colour and texture, prevent browning, extend shelf life and improves sensory parameters of product. Optimization of treatments for minimal processing to withholding product's quality could result in increase of commercial market of minimal processed products.

2.3 Packaging of fruit and vegetables

Food is prone to detoriation due to the action of micro-organisms on the food. Refrigerating the food can only slow down the growth rate of micro-organisms for less time period. In order to increase the shelf life, the addition of either natural preservative (oil, salt, turmeric, etc.) or synthetic preservatives (nitrates, benzoates, propionates, sorbates, sulphites) are required (Rincon and Padilla, 2004). Due to the increased health conscious, consumers are rejecting the products with artificial preservatives. In order to account for all these problems, a new technique called modified atmospheric packaging came into existence. Without addition of preservatives the atmosphere around the product is changed in the packaging. Thiscan be done by using the gases like carbon-dioxide, oxygen, nitrogen and other trace gases (Shih *et. al.,* 2012). Some other gases can also be used but needs the approval from the food authorities. This technique can reduce the micro-organisms growth by controlling the respiration rate of the product inside the packaging. The oxygen should always be at low levels to prevent the oxidation of the product (Gleeson and O'Beirne 2005).

2.3.1 Modified atmospheric packaging

Modified atmospheric packaging (MAP) has many advantages such as, reduction in the growth of harmful micro-organisms, increased shelf life of the product with/without refrigeration, nutritional qualities of the product can be preserved, no change in the natural color of the product, higher acceptance by the consumers due to the no usage of harmful artificial preservatives, etc. (Chauhan *et. al.,* 2006a). Whereas on the other side there are few disadvantages as well. Once the packaging of the product is done, there is no control over the process like controlled atmospheric packaging and higher input cost (Chauhan *et. al.,* 2006b).

Gases are the heart of modified atmospheric packaging. The three main gases used in the MAP are carbon-dioxide, Oxygen, nitrogen. The importance of these three gases is listed below.

2.3.1.1 Oxygen

Oxygen is considered as colorless and odor less gas. Micro-organisms require this oxygen gas for their survival. It also gives the unfavorable color and flavors to the product. The browning index of the product increases due to the oxidation process. So oxygen content should be kept at minimal levels for the proper keeping qualities of the product (Amanatidous *et. al.,* 1999). On the other hand too low content of the oxygen might result in the detoriation of the product. So concentration of the oxygen should be chosen according to the respiration rate of the product (King and Bolin, 1989).

2.3.1.2 Carbon-dioxide

Carbon-dioxide plays an important role in modified atmospheric packaging. Products generally consume oxygen and releases carbon-dioxide. It is effective in preventing the growth of micro-organisms especially aerobic microbes (that respires in the presence of oxygen). For respiring products the carbon-dioxide is kept at low levels and for non-respiring foods the carbon-dioxide is at high levels (Amanatidous *et. al.,* 1999).

2.3.1.3 Nitrogen

Nitrogen is inert in nature and is also called as unreactive gas. It is used as a filler gas in the package. It makes the transportation of the package easier without breaking. The remaining part after filling oxygen and carbon-dioxide is filled with nitrogen (Robertson, 2010).

2.3.2 Different techniques for the atmospheric modification

2.3.2.1 Compensated vacuum packaging

The atmosphere inside the package is removed creating the vacuum inside and then the desired gaseous mixture is flushed inside the package. The desired gaseous mixture contains carbon-dioxide, oxygen and nitrogen. But, this method is not effective than gas flush packaging because there will be no oxygen for respiration of agricultural materials (Hanlon *et. al.*, 1998).

2.3.2.2 Gas flush packaging

The air inside the package is flushed out by filling the desired gaseous mixture which contains carbon-dioxide, oxygen and nitrogen. This is more effective and suitable for the modified atmospheric packaging because desired amount of gases can be flushed to improve the inside environment for respiration of agricultural produce. Here vacuum condition is not created. Here low level of oxygen concentration such as 2%-5% (Lund and McCaul, 2009).

As the respiration rate increases, weight of the product is reduced, shrinkage of the product takes place, breath of the product decreases due senescence andeventually shelf life of the product decreases. The working rule of the MAP is it limits the intake of oxygen and elevates the carbon-dioxide release of the cells thereby reducing the breath rate of the sample (Hine, 1995; Robertson, 2010).

2.3.3 Elements of modified atmospheric packaging

2.3.3.1 Packaging material

During the selection of the packaging material various parameters should be considered. The selection of the packaging material is based on the respiration rate and transpiration rate of the product. If the product in the MAP is respiring product then, the high permeability (ability to allow the gases to pass through it) and low barrier (restricting the passage of gases) packaging film should be used. If the product used in MAP is non-respiring then low permeability and high barrier films should be used (Guillard *et. al.*, 2010). Plastic packaging materials like polyethylene tetra phthalate (PET), polyvinyl chloride (PVC), High densitypolythene (HDPE), Low densitypolythene (LDPE) and polypropylene are used in the modified atmospheric packaging (Brown, 1992; Cowie, 2007; Carraher, 2010; Malpass, 2010).

2.3.3.2 Gas barrier properties

The oxygen intake and carbon-dioxide release process is also continued even after the packaging is done. If the barrier properties of the packaging are high then the carbon-dioxide released might be injurious to fruits and vegetables inside the package. Anaerobic conditions surround the package due to the consumption of all the oxygen present inside and ageing of the product takes place quickly. Micro porous and micro perforated films are developed in order to account for the above problems (Mahajan *et. al.,* 2008; Mauricio *et. al.,* 2011).

2.3.3.3 Mechanical strength

According to Sperling, (2006), mechanical strength of packaging material is an important factor in MAP. If the packaging film has high mechanical strength, its resists the puncture or wear and tear during the processing. But if the material is poor in the mechanical strength the breakage/leakage of the package takes place during the transportation and results in the failure of the MAP. So packaging material must be chosen carefully.

2.3.3.4 Importance of sealing

If the pack is not sealed properly, it might result in the leakage of the gases and alteration of the gases composition inside the package due to the interference of other gases in the atmosphere. Desired gaseous mixture should be maintained inside the package with proper sealing (Scheirs and Kaminsky, 2000; Lucera *et al.,* 2011).

2.3.3.5 Biodegradability and recyclability

Consumers are preferring biodegradable and recyclable packaging materials and they are easily degrades inside the soil without harming the environment. Input costs also reduce if we use recyclable materials as packaging films. But, the problem with biodegradable materials is hydrophilicity. They have low moisture barrier properties and results in the easy growth conditions for microbes. MAP has four appropriate packaging films for packaging of fresh cut fruits and vegetables those are: Polyethylene tetra phthalate (PET), polyethylene, Polyvinyl chloride (PVC) and Poly propylene (Ozeki and Kim, 1996: Joo *et al.*, 2011).

2.3.4 Polymeric materials properties

2.3.4.1 Low density polyethylene (LDPE)

LDPE Material is soft and flexible in nature. Moisture barrier properties are high thus it is having less microbial growth inside package. LDPE is reportedly resistant against various chemicals and sealing of this material is easier. Compared to the other materials it is highly transparent and permeability (allowing the gases to pass through it) is also high (Brown, 1992; Cowie, 2007; Carraher, 2010).

2.3.4.2 High density polyethylene (HDPE)

HDPE material is flexible in nature and has high tensile strength. HDPE is is having higher gas barrier properties. Also, shows high resistance against the moisture and harmful chemicals. Permeability values are very high for the different gaseous mixture and it can be manufactured easily with remarkable high mechanical strength (Marten, 2002).

2.3.4.3 Poly propylene

Thickness is more, so strength is high compared to other materials. Moisture barrier properties also high making it more advantageous and its grease resistivity is also higher than other materials. It has high thermal resistance, so it has potential for heat sealing (Mount, 2009; Malpass, 2010).

2.4 Patents on jackfruit

A patent search strategy was designed based on the common name ‘jackfruit’ along with its botanical name, synonyms, as keywords and concepts in combination with different classification codes such as the International Patent Classification (IPC), Cooperative Patent Classification (CPC) relevant to the technology areas. The search strategy was used toretrieve patents and clinical data from various free and paid databases such as Espacenet, Derwent Innovation Index, Patbase, Chemical Abstracts, Thomson Innovation and Integrity.

Combined results from the above mentioned databases and removal of duplicates retrieved around 199 unique patent families mentioning jackfruit. A further critical review of the results identified 186 patents either claiming jackfruit in general and/or the species *''Artocarpus heterophyllus''* in particular. A major group of 108 patents mentioned the use of jackfruit or parts of the tree in food applications and beverages. 31 patents disclosed the use of jackfruit in agricultural field (include plant breeding, genetic variety, fertilizers, agrochemicals) while 38 patents mentioned the application of jackfruit and other parts of the tree in therapeutics and cosmeceuticals. Another 9 patents disclosing diverse applications were clustered as a miscellaneous category. Figure 2.5, shows the technology matrix built for the above clusters.

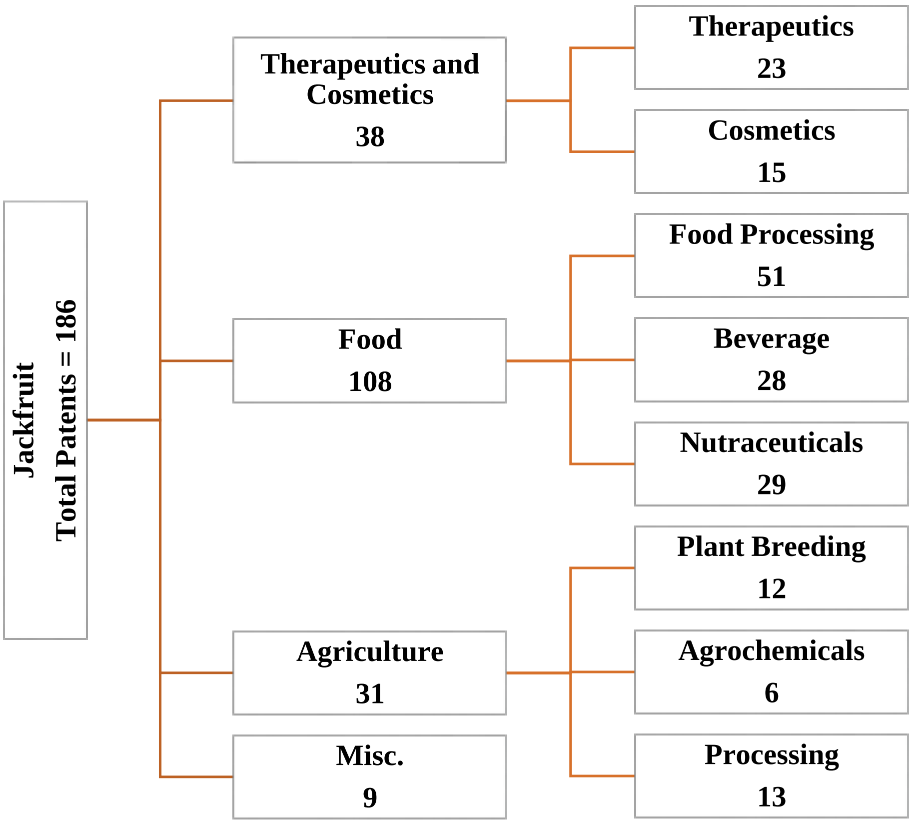

Figure 2.5:Technical area wise distribution of jackfruit patents

Figure 2.6, depicts the patenting activity of all jackfruit related patents in different technical areas over the years for which the publication year was considered for analysis. The earliest publication for therapeutic use was seen in 1990. Increased patenting activity after the year 2010 suggests growing research interest in the field pertaining mainly to use of jackfruit or its bioactive compounds as therapeutic and cosmetic agents, nutraceuticals/ functional food, and preparation of dyes, agrochemicals, bio-wastes for industrial applications. The number of patents filed in 2016 and 2017 would be incompletely represented due to procedural time lag since patents applications are published only after a period of 18 months from the date of filing. The search retrieved patents which focused on methods of cultivation, plant breeding and tissue culture of jackfruit tree, methods of preparing agrochemicals such as pesticides, fertilizers from different parts of the jackfruit tree, processes for preparing various value added food products from jackfruit and their industrial use, methods of extract preparation or isolation of bio-actives from the jackfruit tree, therapeutic applications of jackfruit, its chemical constituents, derivatives and formulations comprising the same for treatment of different conditions. As many references for use of jackfruit as nutritional food items are already available in the prior art, such patents are excluded from the scope of this review. The global distribution of these patents with respect to the priority countries shows that China has the highest number of patent filings (21) followed by Japan (7). Germany and France has two patents each whereas Brazil, India, Korea, Vietnam, UK and the USA have single patent filings. Three patents having priority countries as United Kingdom, United States of America and France have been filed as PCT applications.

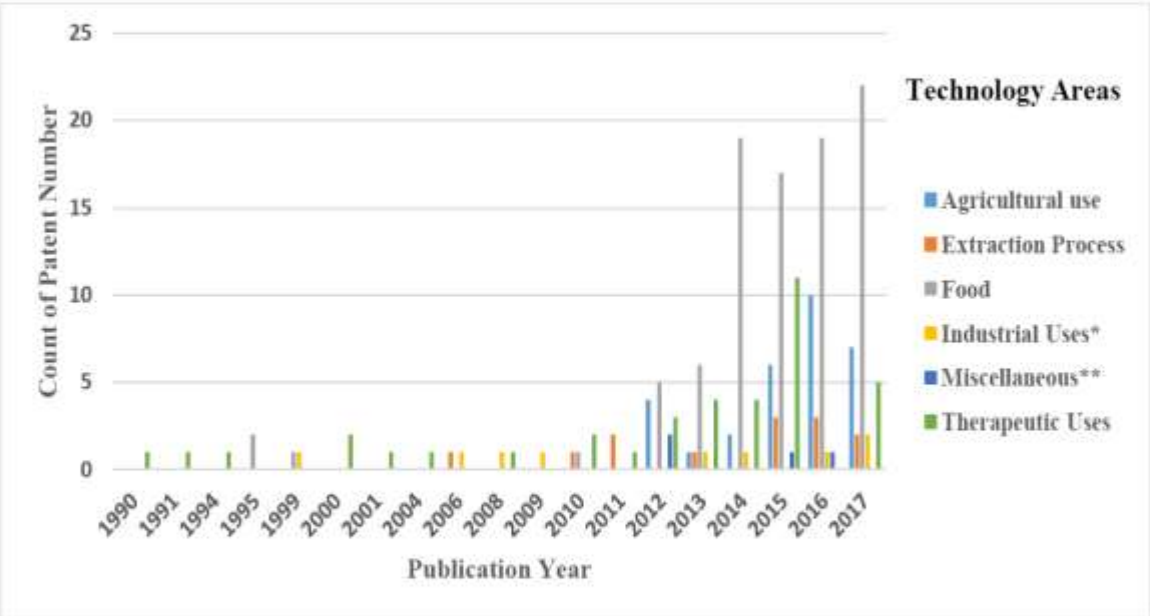

Figure 2.6: Technology wise patenting activity

2.4.1 Data analysis: Applications of jackfruit

A critical review of the selected group of thirty-eight patents disclosing the use of different parts of jackfruit tree and/or the bioactive molecules for different applications is segregated into two major clusters. The highest number of twenty-three patents is grouped under the category for (i) treatment of various disease conditions, followed by fifteen patents disclosing (ii) the use in cosmetics.

Jackfruit (*Artocarpus heterophyllus*) containing various chemical constituents show diverse therapeutic activity such as anti-oxidant, anti-inflammatory, anti-microbial, anti-fungal, and anti-cancer behaviour. Twenty-three patents claiming the therapeutic application of jackfruit and/or its bioactive as an active ingredient in the composition are included under this category and further segregated based on the condition type. A single patents disclosing the use of jackfruit for the treatment of any condition is clustered as other therapeutic uses of jackfruit. The analysis reveals that jackfruit and its phyto-constituents can be used either as single active ingredient or in formulation for the treatment of different conditions.

2.4.2 Different machines and equipment patented on large sized fruits and vegetables

There is always a constant demand for fresh fruits and vegetables throughout the world. The popularity of tender jackfruits in fresh vegetable market has been somewhat limited, the reason behind this was the problems and difficulties consumers had to face in removing the thick, hard peel from tender jackfruit and the sticky latex of the tender jackfruit. (Elevitch and Manner, 2006).

There are several devices reported designed for peeling/ coring and cutting of large sized fruits and vegetables. And also are very popularly in use (Dorsa *et. al.,* 1964; Gusdas 2003). Some effective methods for peeling large sized fruit and vegetables were elaborated and discussed in details in few research and patents (Sijbring, 1969; Neidigh, 1993). The devices enclosed in these patents or researches are not entirely satisfactory working with tender jackfruits because of various reasons related to the practicality and operational aspects. The practical and operational aspects are related to the problems because of thick and hard peel, sticky latex and fast browning of tender jackfruit.

There are various methods for peeling of fruit and vegetables and manual peeling is the most commonly used practice for removing the outer cover of tender jackfruit. In manual method a knife is used to remove the peel. The mustard or coconut oil is used as lubricant on the knife and hands to avoid the stickiness of latex oozed out from the peeled surface.

Chemical peeling of vegetables, this method is the most widely used for peeling sweet potatoes in processing industries. It makes use of a hot solution of sodium hydroxide (Lye) to loosen and soften the skin of the potatoes. But this would not be suited to peeling of other sensitive tuber or non-tuber crops (Aepli *et. al.,* 1975) because a) it may require higher concentration of sodium hydroxide, higher temperature, more immersion time and operation pressure for vegetables that have peels that are tougher than those of potatoes b) When concentration of the Caustic Soda (NaOH) is high, vegetable may need to be immersed in acid solution to neutralize residual Caustic soda. This implies an addition running cost and food poisoning cannot be ruled (Floros, and Chinnan, 1990).

Setty *et. al.,* (1993) reported that peeling was one of the important operations in processing of some fruits and vegetables, meant for canning, freezing, dehydration and pickling. The selection of the proper peeling method was important as the quality of the finished product depended, to a large extent, upon the method used. Sharma and Madhyan, (1988) have developed and evaluated a green pea peeler. The peeler was suitable to peel green pea pods (80.2%) moisture content (wb) at a roller concave clearance of 12 mm and roller speed of 45 rpm. The peeler had the provision of changing the roller surface and roller inclination. The study revealed that kernel recovery of 92.7 per cent with 100 per cent peeling efficiency could be achieved by nailing punched in sheet on the roller using roller inclination of 16°151.

Sheriff *et. al.,* (1995), had evaluated the performance of a power operated cassava peeler at 5 different rotor speeds (950, 1000, 1150, 1400 and 2000 rpm) with size sorted and unsorted cassava tubers. Peeling efficiency and capacity increased with the speed of the rotor. Flesh loss was reduced to 3.67 per cent by peeling of sized tuber at 1150rpm. The optimum capacity of the peeler, the peeling efficiency and the effectiveness were 54 kg/h, 59.33% and 0.57, respectively. Singh *et. al.,* (2013), developed and evaluated the pineapple peeler-cum-slicer. Manual peeling and slicing of pineapple was a time consuming and labour intensive process. Pineapple peeler and slicer were required for reducing the size, obtaining uniform thick slices, proper shape finishing and further processing of pineapple quickly. Therefore, a peeler-cum-slicer was designed with slicing plate of diameter 7cm and core diameter of 2.5cm. It removed the core and produces pineapple rings of uniform thickness and diameter in a single motion. This was a hand operated peeler cum slicer which worked satisfactorily with easy operation. Twenty numbers of pineapple fruits could easily be peeled and sliced by skilled workers in one hour with this device. The designed peeler-cum-slicer had also proved to possess high peeling efficiency (97.2%) with less wastage percentage (5.3%).

Song, (2013), studied on watermelon cutting knife, the utility model discloses a watermelon cutting knife and belongs to the field of articles of daily use. The watermelon cutting knife included a handle, a connecting unit, a first knife, a second knife rest, a first knife body and a second knife body, wherein the connecting unit was arranged on the handle. The first knife rest and the second knife rest were arranged on the connecting unit; the first knife body was arranged on the first knife rest, the second knife body was arranged on the second knife rest and the first knife rest and the second knife rest were detachable; and were rotatable through the connecting unit. Compared with the prior art, the water melon cutting knife could accomplish the cutting of water melons, which an original knife could accomplish and provided another way to cut the water melons which prevents spilling of water melon juice.

2.5 Motivation and research gap

- Lack of published literature on the engineering properties of tender jackfruit.
- For tender jackfruit, no reported study on post-harvest operations like peeling, cutting and packaging.
- No published literature on technology for prevention oxidative browning of fresh cut jackfruit.
- No reported study on determination of proper packaging material for packaging of tender jackfruit.

Tender jackfruit is found to be a high nutritive fruit which contain high amount of vitamins and minerals. The tender Jackfruit is grown in specific season and post-harvest operation such as peeling and cutting is very difficult and done manually with the help of knife. This is due to the unavailability of suitable technology for this fruit. The storing of the fruit is also very difficult due to the enzymatic browning. The common fruit will get a proper post-harvest processing technology so that it can be used as a staple fruit for the season and also value addition of the product will increase the economic value of the particular fruit.

2.6 Problem definition

The prices of the agricultural materials vary according to the supply and demand conditions, which is directly in relation with a season of production and marketing. Jackfruit is a typical horticultural crop, hence it is seasonal and perishable. Because of these characteristics, the jackfruit reportedly fluctuate in price throughout the year. Hence, the fluctuation of prices also affects the returns of growers from a particular crop.

2.7 Objectives of the present work

The specific objectives of this study are to:

1. Analyse the engineering and physicochemical properties analysis of tender jackfruit.
2. Develop methods to minimise the browning of fresh-cut tender jackfruit.
3. Design, fabricate and test a peeling and cutting machine for tender jackfruit.
4. Conduct storage study on for fresh-cut tender jackfruit.
5. Cost economic analysis of the developed machine.

2.8 Summary

The various unit operation has been used for fruits and vegetables for post-harvest processing, preservation and value addition. In case of tender jackfruit, existing traditional practice makes more losses, time-consuming, labour intensive processes, low capacity, injuries, etc. At the local market, home, etc., the pre-mature jackfruit's (tender jackfruit) outer layer is removed manually with the help of a knife, which is time-consuming, injurious as well as handling of gum from jackfruit is very difficult. The storing of the fresh cut jackfruit is also very difficult due to the browning. Therefore, development of efficient technology for processing of tender jackfruit will help to the local tribe/ people to start small processing plant and improve their economic status and also value addition of the product will increase the economic value of the particular fruit.

Chapter 3

Materials and methods

3.1 Sample

The research was carried out at Department of Food Process Engineering, National Institute of Technology, Rourkela, Odisha, India. The jackfruit trees were marked inside the campus and five trees of both hard and soft variety were selected randomly from different sites. These trees were kept under constant observation after the flowering season. Once the fruit started maturing, the samples were collected at various stages from the marked trees. The samples collected from the marked trees were free from any mechanical injuries or microbial infection and thus used for further research. The methodology followed for the research is shown in flow chart (Figure 3.1) and the tender jackfruit before and after cutting into slices is shown in Figure 3.2.

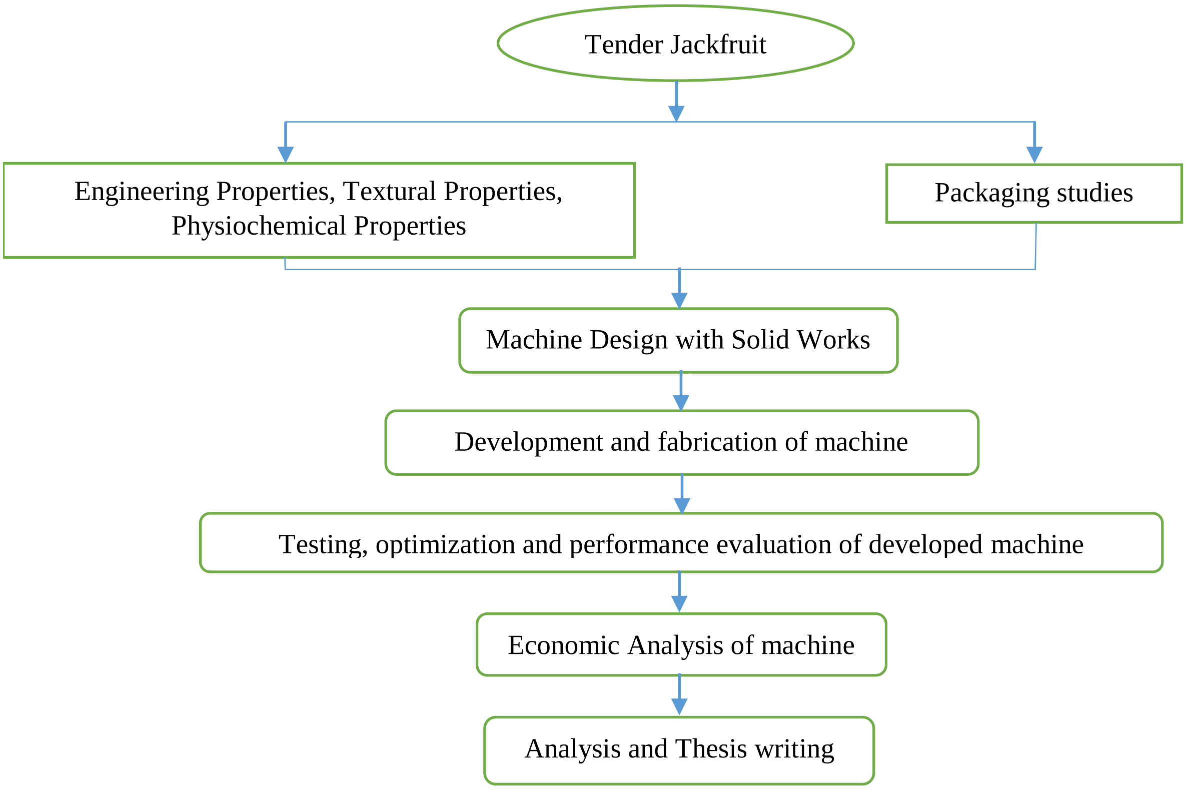

Figure 3.1: Flow chart for research work

Figure 3.2: Pictorial view of tender jackfruit and its slices

3.2 Chemicals used

All the chemicals used for the experiments were of analytical grade. All reagents and chemicals used were purchased from Sigma-Aldrich, USA, Merck & Co, USA and Hi-media, France. The commercial grade filter papers (diameter 125 mm) were procured from Whatman, GE Healthcare UK Ltd., UK and the glassware used for the experiment were obtained from Borosil Glass Works Ltd., Mumbai.

3.3 Analysis of Engineering and physico-chemical properties of tender jackfruit

3.3.1 Physical properties

Physical properties of fruits play important role in design of equipment for various post-harvest processing operations like cleaning, sorting, grading, sizing, pulping, cutting, packing, transportation, and storing. Various physical properties such as principal dimensions, shape, sphericity, surface area, weight, geometric mean diameter, arithmetic mean diameter, peel thickness, etc. were determined as described below.

3.3.2 Weight

The weight of the samples was taken in triplicate by using electronic weighing balances (Indosaw Pvt. Ltd, India). The weight of tender jackfruit was determined using weighing balance of size 0-5kg (least count 1g), whereas, to determine the weight of jackfruit slices etc. the weighing balance with better accuracy and precision was used (least count 0.001g).

3.3.3 Dimensions

The parameters like length, width and thickness were determined with the help of digital vernier calliper (Carbon fibre composite, Fisher Scientific, India) and measuring scale (0-30 cm). The least count for the digital vernier calliper was 0.01 cm (Figure 3.3).

Figure 3.3: Digital vernier calliper

3.3.3.1 Shape

The method used to determine the shape of the fruit is conventional, in case of tender jackfruit. The Jackfruit shape was decided by visual inspection. Since all the fruits are having their characteristic shape of their own, variation within some limit is not considered (Figure 3.4).

Figure 3.4: Shape of jackfruit

3.3.3.2 Arithmetic mean diameter

Arithmetic mean diameter of tender jackfruit is determined by using primary dimensions. The following equation was commonly used to determine the arithmetic mean diameter of the fruit (Pradhan *et. al.,* 2009 and Bianchi *et. al.,* 2016).

$$\text{Arithmetic Mean Diameter (AM)} = \frac{L+B+T}{3} \qquad \dots 3.1$$

Where,

L is the length of tender jackfruit, cm

B is width of tender Jackfruit, cm

T is thickness of tender jackfruit, cm.

3.3.3.3 Geometric mean diameter

Geometric mean diameter of the tender jackfruit was determined by using following equation on the basis of primary dimensions. The standard equation to determine the geometric mean diameter of large fruits and vegetables as mentioned by Pradhan *et. al.*, (2009) and Bianchi *et. al.*, (2016).

$$\text{Geometric Mean Diameter (GM)} = \sqrt[3]{L \times B \times T} \qquad \dots 3.2$$

Where,

L is the length of tender jackfruit, cm

B is width of tender Jackfruit, cm

T is thickness of tender jackfruit, cm.

3.3.3.4 Surface area

The method used to determine the surface area was graphical method. The peel was removed from the tender jackfruit and then peel was spread and plotted on graph sheet. The surface area was determined by counting the total number of squares covered under the peel (Watada *et. al.*, 1996).

3.3.3.5 Sphericity

The other parameter like sphericity percentage edible matter and percentage non edible matter of jackfruit were determined by standard method as reported by Pradhan *et. al.,* (2009) and Bianchi *et. al.,* (2016). The equation used to determine sphericity of tender jackfruit as follow:

$$\text{Sphericity } \emptyset = \frac{\sqrt[3]{L\times B\times T}}{L} \qquad \dots 3.3$$

Where,

L is the length of tender jackfruit, cm

B is width of tender Jackfruit, cm

T is thickness of tender jackfruit, cm.

3.3.3.6 Percentage edible matter

The percentage edible content of tender Jackfruit was determined by weighing the whole sample before cutting and peeling (Singh, 1986). Then the non-edible parts were cut and separated from the fruit. If any non-edible part left it was scraped carefully from the edible part. The following equation was used to determine the percentage edible matter for tender jackfruit (Figure 3.5).

$$\text{Percentage edible matter (\%)} = \frac{\text{Weight of consumable matter (kg)}}{\text{Weight of whole (intact)Fruit (kg)}}\times 100 \qquad \dots 3.4$$

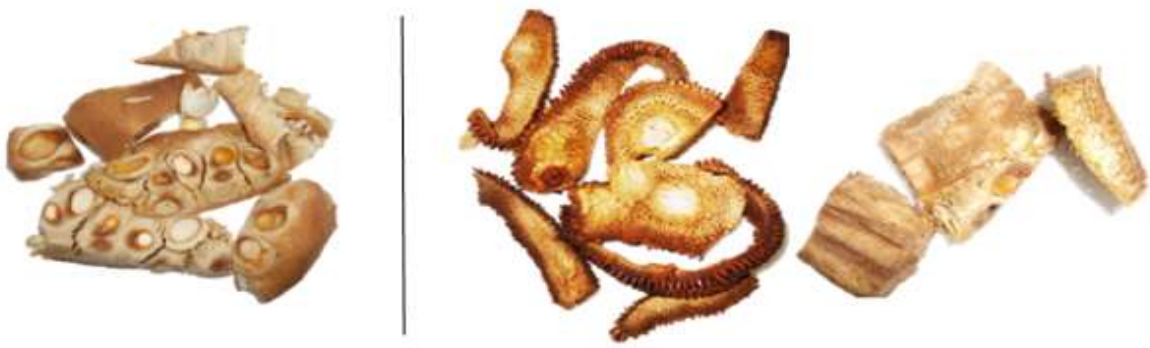

Figure 3.5: Edible portion and non-edible portion of tender jackfruit

3.3.3.7 Percentage non-edible matter

The percentage of non-edible matter in tender jackfruit is mainly consist of non-consumable part like peel and centre core (latex). These parts are weighted and following equation was used to determine the percentage non edible matter in the tender jackfruit (Singh, 1986).

$$\text{Percentage non edible matter (\%)} = \frac{\text{Weight of non-consumable matter (kg)}}{\text{Weight of whole fruit (kg)}} \times 100 \qquad \ldots\ 3.5$$

3.3.3.8 Peel thickness

The thickness of peel is considered to be an important characteristic. To determine the thickness of tender jackfruits the first step was to excoriate peel from the fruit. The peel of tender jackfruit is semi tightly attached to the inner part and when removed from the fruit the little edible portion was remained stick to peel, which was removed using knife. The thickness of peel was then measure with the help of vernier caliper (Singh, 1986).

3.3.4 Chemical properties

Chemical properties were determined at an average moisture content of 78.5±5.8% (w.b). These chemical properties play important role in the processing of tender jackfruit. Procedures followed for determination of chemical properties are explained below.

3.3.4.1 Moisture content

Samples (5g) in triplicate were dried for 24 hours in hot air oven (Figure 3.6) at 105ºC (AOAC, 2000) in pre-weighed crucibles. The crucibles were transferred immediately to desiccators. It was then cooled and weighed. The loss in weight was noted as the moisture content of the samples.

$$\text{Moisture content (\% w.b.)} = \frac{\text{loss in weight (g)}}{\text{weight of sample (g)}} \times 10 \qquad \ldots\ 3.6$$

Figure 3.6: Hot air oven for determination of moisture content

3.3.4.2 Ash content

Dried sample (5g) was taken in a pre-weighed crucible. Charring was performed on a hot plate.The charred sample was placed on a muffle furnace at 600^{o}C for 4 hours (AOAC, 2000).The ratio of residue left in crucibles after ashing to the initial weight of sample gives the ash content of the sample.

$$\text{Ash content (\%)}=\frac{\text{weight of residue after ashing(g)}}{\text{weight of sample(g)}}\times 100 \qquad \dots 3.7$$

3.3.4.3 pH

pH of the tender jackfruit was measured using a pH meter (pH-700, Eutech, USA). Standard operating procedure was followed for the measurements. The equipment was standardized with a buffer solution of pH 4, 7 and 10. The knob was dipped into the sample and readings were recorded (Figure 3.7).

Figure 3.7: Determination of pH using pH-meter

3.3.4.4 Total soluble solids

The total soluble solid (TSS) of the samples were determined using a digital Refractometer (MAH-71, Milwaukee, USA). The TSS values were expressed as degree Brix (ºBrix).

3.3.4.5 Total dissolve solid

Total dissolve solid of the samples were determined using digital TDS meter (TDS-3, HM digital, India). The value for TDS was directly provided in digital display.

3.3.4.6 Crude protein

Crude protein was determined using Kjeldahl apparatus (Classic-Dx-Vats-E, Pelican Equipments, India) (Figure 3.8). Fresh sample (0.5g) was digested with nitrogen-free sulphuric acid (20ml) using digestion mixture (10g) containing a catalyst of potassium sulfate and copper sulfate (9:1). The solution was cooled and transferred to 100ml volumetric flask. The volume was made up to the mark with distilled water and mixed. A measured sample (10ml) was taken for distillation process addition. Liberated ammonia was trapped in hydrochloric acid (0.01N) containing methyl red indicator and then titrated with (0.01N) sodium hydroxide. Total nitrogen content was calculated using equation 3.8. Nitrogen present in the sample was used to calculate percent crude protein by using a factor of 6.25 using equation 3.9 (AOAC, 2000).

$$\text{Nitrogen (\%)} = \frac{\text{sample titre-blank titer} \times \text{normality of acid} \times 14 \times 100}{\text{weight of sample} \times 1000} \qquad \ldots 3.8$$

$$\text{Crude protein(\%)} = \text{\% nitrogen} \times 6.25 \qquad \ldots 3.9$$

Figure 3. 8: Kjeldahl apparatus

3.3.4.7 Crude fat

The fat content of the fresh sample was determined using socsplus extraction system (SES-06 AS DLSTS, Pelican Equipments, India) (Figure 3.9) Dried sample (5-10g) was transferred to fat extraction thimble. Fat was extracted using Petroleum ether. The excess solvent was removed and evaporated. The fat content was calculated using equation 3.10.

$$\text{Fat }(\%)=\frac{\text{Weight of fat (g)}}{\text{Weight of sample (g)}}\times 100 \qquad \ldots 3.10$$

Figure 3.9: Socsplus extraction system

3.3.4.8 Crude fibre

Crude fibre was determined by Fibra plus (FES-06 AS DLSTS, Pelican Equipments, India) (Figure 3.10). A defatted sample (2-3g) was digested sequentially using a hot digestion diluted acid and alkaline solution. The remains of digested sample was dried and put in muffle furnace at 450ºC for 3 hours. The difference in weight from the initial fresh sample to the ash-dried sample is the amount of crude fibre present in the fruit.

Figure 3.10: Fibra plus apparatus for fiber analysis

3.3.4.9 Carbohydrates

Available carbohydrate was calculated by subtracting the sum of crude protein, crude lipid, crude fibre, and ash from 100% of dry weight sample. (Serrem *et. al.,* 2011; Benhura *et. al.,* 2012).

3.3.4.10 Ascorbic acid

A modified method of Daood et al., (1994) was used for the extraction of vitamin C from tender jackfruit. A 10g portion of jackfruit samples was homogenised with 40ml of a solution of 3% metaphosphoric acid in 8% glacial acetic acid, pH 1.5, for 1min using a blender. The extract was then mechanically shaken for 15min in darkness. After filtration the clear extract was stored at −18°C prior to analysis by the 2,6-dichloroindophenol titrimetric method

3.3.4.11 Mineral analysis

Dried sample (0.5g) was digested in concentrated HNO_3 (AOAC, 2000). The minerals (Calcium, Sodium and Phosphorous) were analyzed by flame atomic absorption spectrophotometer (AAS Analyst 200, Perkin Elmer, USA) (Figure 3.11). All mineral standards used for this purpose were of analytical grade (Sigma-Aldrich, India).

Figure 3.11: Flame atomic absorption spectrophotometer

3.3.4.12 Total energy

The energy of the fruit was calculated using percentage method suggested by water specific factors for fruits (Watt and Merill, 1978). The following equation was used to determine the total energy of the samples (James, 1999).

$$\text{Energy value of food (in kJ/100 g)} = [(\text{\% available carbohydrates x } 17) + (\text{\% protein x } 17) + (\text{\% fat x } 37)] \quad \ldots 3.11$$

3.3.4.13 Browning index

Browning index (BI) was measured to estimate the browning in jackfruit slices. The procedure followed was, 5 g sample was extracted in 100ml ethanol (67%) for 60min. Then the extract was filtered by using filter paper (Whatman filter no.1). Then filtrate was used to determine browning index by using UV-visible spectrophotometer (wavelength at 420nm) (Figure 3.12) with blank as 67% ethanol (Sexena *et. al.*, 2009).

Figure 3. 12: UV-visible spectrophotometer

3.3.4.14 Total phenols

The total phenol is defined as equivalent mg of Gallic acid in 100g of sample. The phenol content in tender jackfruit first extracted by using methanol solution. Basically 5g sample was taken and added to 50 ml of methanol solution. The extract thus obtained was diluted with distilled water in 1:10 (1ml of extract 9 ml of distilled water). Then to this mixture, 1ml of Folin-Ciocalteu (FC) reagent was added and vigorously shaken. After few min, 10ml of 7% of sodium carbonate solution was added to the sample and finally the volume was make upto 25ml with distilled water. It is followed by the incubation of 90min in the temperature range of 25-30°C. Finally, UV-visible spectrophotometer equipment was used to record the absorbance value if the sample against the blank reagent, by illuminating with monochromatic light of wavelength of 750mn (AOAC, 1997).

3.3.4.15 Total flavonoids

The $AlCl_3$ method adapted from Lamaison and Carnet, (1990) was used for the determination of total flavonoids. An aliquot (1.5ml) of each extract was added to an equal volume of a solution of 2% $AlCl_3 \cdot 6H_2O$ (2g in 100ml of methanol) and thoroughly mixed. The mixture was vigorously shaken and the absorbance was read at 367.5nm after 10min of incubation. Results were expressed in mg quercetin g^{-1} of fresh weight.

3.4 Textural properties

Hardness of the fruit was measured by Texture Analyser (M/08-371-CT3, Brookfield, USA) (Figure 3.13). Compression test and tensile test were done by using texture analyzer to determine hardness. Hardness of fruit pericarp, cutting resistance, and force required for peel the pericap were measured.

Figure 3.13: Texture analyser

The peak force at the first compression was considered as the surface hardness of the fruit (Harker *et. al.,* 2002). It is the resistance to indentation, and it is determined by measuring the permanent depth of the indentation (Kinzey &Norconk, 1990). The testing parameters of texture analyzer were kept constant throughout for the probe (TA-MTP). Pre-test speed, test speed, post-test speed were maintained at 1, 0.5, and 0.5 mm/s respectively. A load cell of 10000g was used for the purpose and the trigger force was kept at 0.50 N.All these experiments were replicated for five-time for accuracy of the data. The whole fruit was kept on the base table for providing quick and easy height adjustment to accommodate the sample and allowed to penetrate the probe inside the sample.

3.4.1 Firmness

The firmness of the jackfruit is a textural property. Firmness can be defined as the maximum force (N) recorded. Texture profile of jackfruits were measured using CT3 texture analyser [probe: needle probe (TA9, 20mm L), pre-test speed: 1.00 mm/s, test speed: 0.50 mm/s, post- test speed: 0.5 mm/s; load cell: 10000g]. The resistance of the material to these force is measured by a calibrated load cell and results were shown in either grams or Newton. The sample was kept on the base round table for providing quick and easy height adjustment to accommodate the sample and allowed to penetrate the probe inside the sample. The results were taken from the installed Texture Pro CT Software.

3.5 Colour properties

The colour of the fruit was measured using a colorimeter (ColorFlex EZ,Hunter Lab, USA) (Figure 3.14). Colour readings were taken along the equatorial axis of the fruit. Readings of each color index in the Hunter scale (L, a, b) were taken in triplicates.

Figure 3. 14: Colorimeter

The equipment was calibrated against white tile (L*= 94.19; a*=-1.38; b*=-0.28) and black tile (L*=0.03; a*=0.02; b*=-0.04). 'L' value indicates inclination towards black (L=0) or white (L=100). Positive and negative 'a' value indicates inclination towards redness or greenness, respectively. Positive and negative 'b' value indicates inclination towards yellowness or blueness, respectively. The total color change (ΔE) was calculated using the equation 3.12 (Mohammadi *et al*., 2008).

$$\Delta E=\sqrt{(L_0-L)^2+(a_0-a)^2+(b_0-b)^2} \quad \ldots 3.12$$

where,

L_o, a_o and b_o are reference values of colour;

L, a and b are the samples values of colour

3.6 Image analysis

Sample images was captured by DSLR camera (24.3 MP Nikon D-5300, D-SLR, Minato, Tokyo, Japan). With the help of tripod stand the camera was carefully fixed at 30 cm (approximately) away from the sample. A black chart/mat was used to provide as background for the sample and photographed subsequently. A dark/low light room at normal temperature and pressure was used for the experiment. JPEG format of photographs were analysed with the help of MATLAB image processing toolbox (version 8.3 Mathworks, Natick, MA, USA) to quantify the browning precisely.

Two methods were used to estimate the degree of browning in tender jackfruit slices (Schwarz, Cowan, & Beatty, 1987).

Methods are as follow.

The changes in CIE (L*, a* and b* values) were determined and examined by using algorithms in connection with colour space conversion based on the RGB colour space. Where L* – signifies brightness/lightness, a* – signifies redness and b* – signifies yellowness.

The changes in RGB colour values were determined for each channel (R, G, and B) individually. Where R stands for red colour, B means blue and G stands for green. The colour range varies from 0 to 255.

3.7 Microbial analysis

Using separate sterile pipets, decimal dilutions of 10^{-2}, 10^{-3}, 10^{-4}, and others as appropriate, were prepared. Homogenization of sample was done by transferring 10ml of previous dilution to 90ml of diluent. Sampling foam was avoided during homogenization. All dilutions were shaken 25 times in 30cm (1ft) arc within 7s. 1ml of each dilution was pipette into separate, duplicate, appropriately marked petri dishes. Dilution bottle was reshaken 25 times in 30cm arc within 7s. 12-15ml plate count agar (cooled to 45±1°C) was added to each plate within 15min of original dilution. Immediately, sample dilutions and agar medium were mixed thoroughly and uniformly by alternate rotation and back-and-forth motion of plates on flat level surface. Let agar solidify. Invert solidified petri dishes, and incubate promptly for 48±2 h at 35°C.

Normal plates (25-250) and spreader-free plates were selected and all colony forming units (CFU) were counted, including those of pinpoint size, on selected plates. Dilutions used were recorded and total number of colonies were counted.

3.8 Storage study

The storage study was performed only on freshly peeled, cut and processed jackfruit slices. The fresh cut tender jackfruit slices were packed in modified packaging conditions and experiments were done to determine the optimum conditions to store the jackfruit slices for relatively longer time.

3.8.1 Packaging treatment

The slices of fresh cut tender jackfruit were packed in different packaging materials like Low density polyethylene (LDPE; 20 Microns), High density polyethylene (HDPE; 80 Microns), Polypropylene (PP) after treatment. The packaging conditions are also varies by varying the gas concentration inside the package. The packaging of slices (Figure 3.15) was done with the help of modified atmospheric packaging machine (MAP) (Compact packaging machine, 300W, Shri balaji Industries, India). The size of each package was maintained to contain 200g of fresh cut jackfruit slice. Then the storage study was caries out on jackfruit slices. These conditions were used for the packaging and the quality of the packaged products was be evaluated by measuring the dependent parameters such as chemical analysis, colour, texture and microbial growth.

Figure 3.15**:** Packaging treatment of fresh cut tender jackfruit

3.8.2 Head space analysis

The gas analysis inside the package was done with the help of bench top headspace analysis instrument (CheckMate 3 Headspace Gas Analyzer, Dansensor, USA) (Figure 3.16) that combined oxygen/carbon dioxide analysis of gas-flushed to the packages. A thin needle is inserted into the package and a pump draws a small sample of precise volume of headspace gas into the analyzer equipment. The headspace gas comes into contact with a sensor that can measure the concentration of residual oxygen or carbon dioxide in the headspace gas sample.

Figure 3.16: Headspace gas analyser

3.9 Sensory properties

The sensory evaluation of jackfruit was done on the basis of its colour, odour/smell, texture/ freshness, and overall acceptance. The most popular method nine point hedonic scale was used (Larmond, 1977) and the team of 10 trained panelists were selected. The product overview was presented to the panellists before the evaluation. The sensory evaluation was conducted in ideal conditions. The scores assigned to each parameters were 1 to 9, where 1 stands for extremely dislike and 9 stands for extremely like. The samples were coded and randomly drawn by the panelists (Ranganna, 1986).

3.10 Statistical analysis

Second order polynomial model was used to determine the response data from central composite design, the equation used was given below.

$$Yi = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta11X12 + \beta22X22 + \beta33X32 + \beta12X1X\,2 + \beta13X1X3 + \beta23X2X3 \quad \ldots\ 3.13$$

where,

Y – Predicted response

X1, X2, X3 – Response variables

β0 – Regression co-efficient of fitted response at centre point

β1, β2 and β3 – Regression co-efficient for linear effect terms

β11, β22 and β33 – Regression co-efficient for quadratic effect terms

β12, β23 and β13 – Interaction effect

The equation used is describing the effect of each independent variable, the combined effect of the independent variables and the interaction effect of independent variables on the response variable (Y). To determine the optimum conditions the contour plots of the interactions between independent variables over the responses were generated. Parameters used to find the acceptability of polynomial model were R^2 value, lack of fit and significance by ANOVA at $p>0.05$. The good fit of model was considered when R^2 was more than 0.8. The graphical representation was used for the optimization of the working condition and maximizing the responses.

In case of image analysis, Experimental design is based on completely randomized design and all the experiments were performed in triplicate. The SPSS for window version 10 (SPSS Inc., Illinois, USA) was used to perform ANOVA. The statement of significance was based on $p>0.05$ unless otherwise indicated. Pearson's test and Duncan’s multiple range test were done to find out correlation coefficients for image analysis and sensory test.

3.11 Design and fabrication and optimization of peeling cum cutting machine

3.11.1 Material selection and fabrication

The machine was designed using SolidWorks-2015. The mechanical and textural properties of the fruit were taken into consideration for the design. Selection of material for fabrication of the machine was done based on suitability of the material in food application. As fruit size varies from small to very large, the machine was designed to have the ability to work for all sizes of fruits.

3.11.2 Design consideration computation

The following considerations were made during the design of the machine components:

a. Average dimensions and mass of the fruit.
b. Hardness and cutting strength of fruit
c. Browning of fresh cut tender jackfruit
d. Capacity
e. Availability of the construction materials
f. Cost of construction materials
g. Feasibility for fabrication
h. Ease of operation of the designed machine
i. Prolonged life of the machine

3.11.3 Description of the machine

3.11.3.1 Mainframe

The mainframe of the machine provides a platform for various other parts to be assembled. It provides the support and strength to the machine both during static and working condition. It was made out of mild steel angle iron sections. Two design factors considered in determining the material required for the frame were weight and strength of the material.

3.11.3.2 Prime mover and power transmission devices

Calculation of horsepower requirement was done using the following formula (Khurmi and Gupta, 2005);

$$hp = \frac{2\pi NT}{75x60} \qquad \dots 3.14$$

where,

N is the speed of the shaft, rpm;

T is the torque on the shaft = 2.52 kg-m.

Power was transmitted from the motor to the main rotor by means of 'V' belts and pulleys. Driven pulley diameter (D2) in (m) was determined from equation 3.15 (Adonis *et. al.*, 2016).

$$N1D1=\mu N2D2 \qquad \dots 3.15$$

where,

D1 is the diameter of the driving pulley, (m)

D2 is the diameter of driven pulley,(m)

N1 is speed of the driving pulley, (rpm)

N2 is speed of the driven pulley (rpm),

μ is the speed reduction ratio.

The bearing selection was based on its load carrying capacity, life expectancy, and reliability. The gear train has a better advantage than belt drive to increase velocity ratio, transmit large power and has reliable service than the belt (Ikechukwu and Okonkwo, 2014). The arrangement was made in the gear connections so that the feed rollers rotate in opposite direction.

3.11.3.3 Main shaft

The main shaft ensures satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. The following formula was used for designing the shaft (Thirupathi *et. al.*, 2006; Dickson, 2015).

$$T = \frac{\pi}{16} f_s d^3 \quad \ldots 3.16$$

where,

f_s is the maximum allowable shear stress, kg/m^2 [3.5 kg/m^2];

d is the diameter of the main shaft, i.e. cm;

T is the torque, kg-cm. F (kg) x L (m) = 0.36 x 7 = 2.52;

L is the length of flat (c/c distance from shaft and flat);

F is the force required to crush the fruits 0.36 kg (3.6 N).

It was assumed that the force is acting in the middle of the main shaft with a safety factor of 1.5. The peripheral speed was determined using equation 3.17 (Olaoye, 2011);

$$V_s = \frac{\pi d N}{60} \quad \ldots 3.17$$

where,

V_S is the peripheral speed (m/s),

d is the shaft diameter (m),

N is the speed of the main shaft (rpm).

3.11.4 Working principle of the machine

The machine (Figure 3.17) was designed and developed, which can process all sizes of tender jackfruit (Length: 8 to 30cm and diameter: 7cm) with the design capacity of 12 jackfruits/hr or more. All food contact parts of the machine are made up of Stainless Steel-Grade 304. The designed machine is be capable of washing, peeling and cutting of tender jackfruit effectively. Machine is completely protected from all sides to prevent any chances of accidents or hazards to operator, for this topline or high strength plastic was used.

Washing or water treatment assembly:

a. The chemical solution spray over jackfruit while washing and peeling operations.
b. Capacity of water/ chemical holding tank is more than 40 litres.

c. A pump (with discharge controlling provision) in tank so that turbulence can be created in tank and treatment water can be supplied to at required destination

Peeling assembly:

d. The peeling assembly consists of adjustable platforms to hold any size of jackfruit firmly (Length: 8 to 30cm and diameter: greater than 7cm).
e. The hollow shaft to spin the jackfruit on its longitudinal axis is (internal diameter cm and external diameter cm) driven by motor, which have provision to control its rpm.

Cutting assembly:

f. Cutting assembly contains roller blades with serrations on the sharp edges to cut the jackfruit in small slices (thickness of 4.5cm).
g. Cutting is mechanically done with provision to control the speed of cutting.

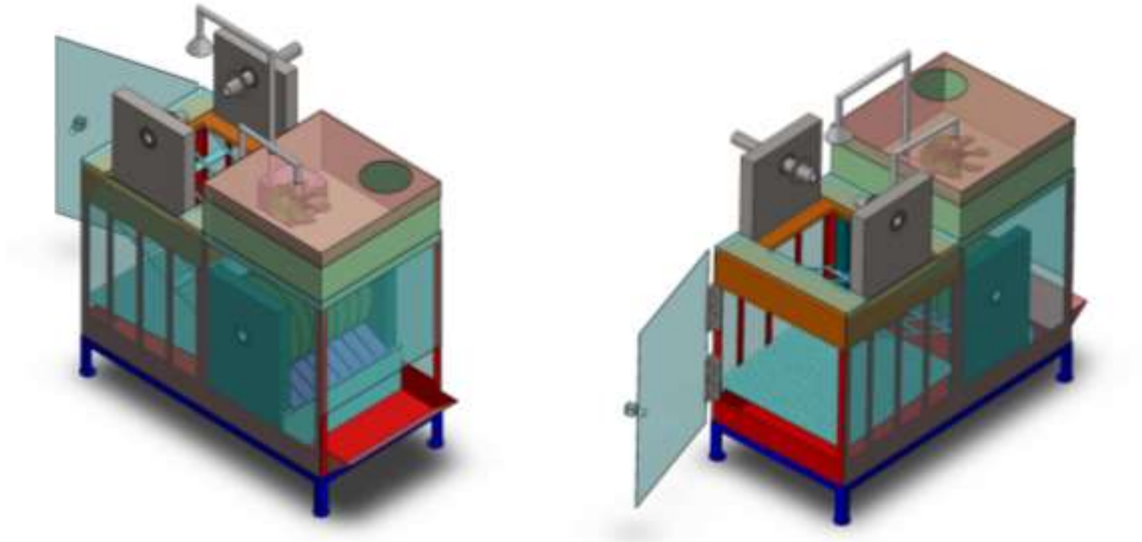

Figure 3. 17: Isometric view of developed machine

3.11.5 Performance evaluation

3.11.5.1 Throughput capacity (kg/hr)

Throughput is the maximum rate of production or the maximum rate at which tender jackfruit can be processed (peeling, cutting and treatment). It was measured by using the equation as below (Olaoye, 2011):

$$\text{Throughput capacity} = \frac{\text{Total weight of fruit subjected to processing (kg)}}{\text{Operating Time (h)}} \quad \ldots 3.18$$

3.11.5.2 Effective throughput capacity (kg/hr)

Throughput capacity is basically the flow of material through the machine but it is not related to the effectiveness of machine. The effective throughput capacity is the rate of machine to produce the end product. It was determined by using following equation. The weight of jackfruit after processing was measured to determine the effective throughput capacity.

$$\text{Effective throughput capacity} = \frac{\text{Actual weight of processed fruit (kg)}}{\text{Actual operating time (h)}} \qquad \ldots 3.19$$

3.11.5.3 Labor requirement (man-hours/quintal)

The total number of working hours required to process per 100 kg of product is known as labor requirement and was found by using following equation:

$$\text{Labor requirement} = \frac{1}{\text{Throughput capacity}} \times 100 \qquad \ldots 3.20$$

3.11.5.4 Peeling co-efficient (%)

The weight of jackfruit was measured before peeling and after peeling it by machine to determine the peeling coefficient. The peeling coefficient was determined by using following equation.

$$\text{Peeling co-efficient} = \frac{\text{Weight of jackfruit after peeling (kg)}}{\text{Weight of jackfruit (kg)}} \times 100 \qquad \ldots 3.21$$

3.11.5.5 Peeling loss (%)

It is the measure of losses occurs during the peeling. The machine is having its own limitations which were measured by measuring the peeling loss. The weight of jackfruit was measured before peeling and after peeling the consumable part was separated from the peel portion and weighed. The following equation was used to determine the peeling losses.

$$\text{Peeling loss} = \frac{\text{Weight of consumable portion remained in peel after peeling (kg)}}{\text{Total weight of jackfruit (kg)}} \times 100 \qquad \ldots 3.22$$

3.11.5.6 Peeling time (min/kg)

It is the total time needed for a jackfruit to completely peel. This peeling time include time needed to mount the jackfruit on machine and time needed to completely peel it at set rpm. The following equation was used to determine the peeling time.

$$\text{Peeling time} = \frac{\text{Time taken to peel the jackfruit (minutes)}}{\text{Weight of the jackfruit (kg)}} \qquad \ldots 3.23$$

3.11.5.7 Efficiency of cutting machine (%)

The cutting efficiency of the machine was measure by determine the rate of cutting of machine of tender jackfruit (kg/h) and by determine the cutting rate of manual cutting of tender jackfruit (kg/h). The professional labor was taken for the process. The jackfruit was first manually peeled and for cutting efficiency, only the cutting time was used and peeling time was not considered. The following equation was used to determine the cutting efficiency of the machine (Henning *et. al.*,2012) .

$$\text{Efficiency of cutting machine} = \frac{\text{Rate of machine cutting}}{\text{Rate of manual cutting}} \times 100 \qquad \ldots 3.24$$

3.11.5.8 Cutting loss (%)

It is the measure of losses occurs during the cutting of peeled jackfruit. The weight of consumable portion of jackfruit was measured after peeling and after cutting. The following equation was used to determine the peeling losses.

$$\text{Cutting loss} = \frac{\text{Weight of consumable portion remained after cutting (kg)}}{\text{Total weight of jackfruit (kg)}} \times 100 \qquad \ldots 3.25$$

3.11.5.9 Effective segment area

Effective area of each segmented blade is calculated as follow (Henning *et. al.*,2012)

$$A_s = \frac{\propto}{360}\left(\pi\left(R^2 - (R-h)^2\right)\right) \qquad \ldots 3.26$$

where,

A_s is the effective segment area, m^2

R is the radius of the blade, m

h is the segment height measured, m

α is the effective angle of the segments area.

3.11.6 Optimization of machine operational parameter

To optimize the performance of the developed machine studies were conducted on various machine parameter, viz., rpm of peeling pulley, rpm of cutting blade and peeler forward speed.

The following were taken for experiments:

Table 3.1: Independent and dependent variables for experiment

Variable	Level
Peeler pulley speed	20 to 325 rpm
Peeler forward speed	15 to 105 rpm
Cutter speed	50 to 500 rpm
Performance indicator	
Peeling efficiency	
Peeling loss	
Peeling time	
Cutting efficiency	
Cutting loss	

Experiments were conducted on developed machine at optimized conditions. The effect of machine parameters on the various performance parameters (peeling efficiency, peeling loss, peeling time, cutting efficiency, cutting loss) were determined.

3.12 Cost analysis

The cost economic analysis of the fabricated machine was done based on the guidelines provided by the Ministry of Micro, Small and Medium Enterprises (MSME), Govt. of India and Food and Agricultural Organization (FAO). Various parameters viz. Benefit-Cost Ratio (BCR), Pay-Back-Period (PBP), Return-On-Investment (ROI), and Break Even Point (BEP) were calculated following standard procedure. Fixed cost, variable cost, the values of revenue generated and the annually earned profit for the developed machine was considered. These data were analyzed by the standard formula as given below (Leon *et. al.*, 2002; Gahoonia *et. al.*, 2005);

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\text{Total annual revenue from fruit processing, Rs}}{\text{Annual Present value of fruit, Rs.}} \quad \ldots 3.27$$

$$\text{Return On Investment (ROI)\%} = \frac{\text{Total annual revenue from fruit processing, Rs.}}{\text{Annual variable cost, Rs.+ Annual Fixed cost, Rs}} \times 100 \quad \ldots 3.28$$

$$\text{Pay Back Period (PBP)} = \frac{1}{\text{ROI}} \quad \ldots 3.29$$

Pay-Back-Period (PBP) refers to the period required to recover the funds expended in an investment or to reach the break-even point.ROI is the ratio of a profit or loss made in a year expressed in terms of an investment and shown as a percentage of increase or decrease in the value of the investment during the year in question (Kader, 2004). Cost of processing 1kg of jackfruit can be calculated as the amount of rupees required to process a kg of jackfruit by dividing the total annual operating cost and the machine cost to the annual processing capacity for the raw material.

Break Even Point (BEP) analysis helps us to determine the break-even production capacity to avoid losses. BEP also refers to the amount of sales value at which no profit or loss in a business (Escobar et al., 2009). At the initial stage in calculating the break-even point, the cost is divided into two broad categories, fixed cost, and variable cost. These categories maybe defined by a fixed cost that remains constant irrespective of changes in the volume of output whereas the variable costs which vary directly with output. It can be calculated as:

$$\text{BEP (sales)} = \frac{\text{Annual fixed cost}}{\text{Annual unit sales} - \text{Annual unit variable cost}} \quad \ldots 3.30$$

Chapter 4

Results and discussion

4.1 Analysis of engineering and physicochemical properties of tender jackfruit[1]

4.1.1 Physical properties

Based on the fruit size the grading system of jackfruit was developed. Based on size (length), jackfruit can be divided in three categories i.e. small (<15 cm), medium (15.1-25 cm) and large (>25.1 cm) (Singh, 1986). Although the jackfruit are grown in all sizes and shapes, but selected for the purpose of marketing, jackfruit of uniform sizes and regular shapes were preferred whereas, larger and smaller fruits are sold locally. Another effective grading system is based on the maturity, jackfruits can be classified in two forms i.e. tender form and ripen form. The following criteria has been taken (Sidhu, 2012) for further subdivision of tender and ripen jackfruit and their physical properties are reported.

	Stages	Description
Tender	Stage 1	No formation of seeds or fruitlets. Texture like chicken and used for cooking and pickle making.
	Stage 2	Seeds and fruitlets are just started to grow and can find very small or baby seeds while cutting. Best used as vegetable.
	Stage 3	Seeds and fruitlets are immature and fully developed buttesta in seedis not developed yet. Seeds are edible as vegetable without cleaning.
	Stage 4	Fully developed seeds and fruitlets. Testa of seed is developed. Best stage for making chips and use for various curry preparations.

4.1.1.1 Weight and dimensions

Both varieties of tender jackfruit were appeared to oblong (near to be cylindrical) in shape. Therefore, average values of two principal dimensions of jackfruit (i.e. length and diameter) and weight was determined at different stages in this study and tabulated in table

[1] This work has been published as Rana, S.S., Pradhan, R.C., & Mishra S. (2018). Variation in properties of tender jackfruit during different stages of maturity. *Journal of food science and technology,* 1-8. *(SCI journal)*

4.1. Each linear dimension and weightwas found to be linearly dependent on stages of maturity for both hard and soft varieties. The significant expansion of size can be seen easily in both the varieties of tender jackfruit from stage 1 to 4. For hard variety the weight and dimensions of 50 fruits were measured at stage 1 such as: weight 1.42±0.76kg, length 12.54±5.78cm and diameter 8.02±3.22cm. Increase of 121.12%, 46.09% and 75.93% of weight, length and diameter, respectively, in mean weight and dimension were observed due to change in stage 1 to 4. The differences between the values were statistically significant at P<0.05. The observations were similar in case of soft variety. Increase of 60.80%, 57.63% and 119.77% of weight, length and diameter, respectively, in mean weight and dimension due to change in stage 1 to 4 (P<0.05) was observed.

Table 4. 1: Physical properties of two varieties of tender jackfruit at different stages of maturity.

Hard variety				
Properties	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Weight (kg)	1.42 ± 0.76^{a}	2.57 ± 0.53^{b}	3.05 ± 0.62^{c}	3.14 ± 0.83^{c}
Shape	Sphere	Sphere	Oblong	Oblong
Length (cm)	12.54 ± 5.78^{a}	16.04 ± 4.92^{b}	18.08 ± 6.69^{c}	18.32 ± 7.43^{c}
Diameter (cm)	8.02 ± 3.22^{a}	11.97 ± 2.99^{b}	14.15 ± 4.34^{c}	14.11 ± 3.96^{c}
Geometric mean diameter (cm)	9.65 ± 3.12^{a}	12.39 ± 3.12^{b}	$15..06 \pm 2.11^{c}$	15.37 ± 2.31^{c}
Arithmetic mean diameter (cm)	9.55 ± 2.65^{a}	12.67 ± 3.78^{b}	15.24 ± 3.12^{c}	15.49 ± 4.66^{c}
Sphericity	0.91 ± 0.03^{a}	0.89 ± 0.01^{b}	0.81 ± 0.06^{c}	0.83 ± 0.06^{d}
%age edible matter	63.41 ± 3.54^{a}	59.11 ± 1.4^{b}	54.98 ± 3.21^{c}	55.57 ± 4.6^{c}
%age non edible matter	35.44 ± 4.56^{a}	38.88 ± 4.2^{b}	43.15 ± 2.17^{c}	43.63 ± 0.25^{c}
Surface area (cm^2)	980.60 ± 113.30^{a}	1304.90 ± 97.40^{b}	1507.90 ± 163.30^{c}	1534.50 ± 189.50^{c}
Soft variety				
Properties	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Weight (kg)	1.25 ± 0.52^{a}	1.44 ± 0.63^{b}	1.73 ± 0.47^{c}	2.01 ± 0.51^{d}
Shape	Oblong	Oblong	Oblong	Oblong
Length (cm)	8.45 ± 4.54^{a}	10.64 ± 3.68^{b}	12.59 ± 4.98^{c}	13.32 ± 5.16^{d}
Diameter (cm)	4.45 ± 1.72^{a}	6.32 ± 1.67^{b}	7.65 ± 2.11^{c}	9.78 ± 2.99^{d}
Geometric mean diameter (cm)	5.15 ± 1.19^{a}	7.19 ± 1.43^{b}	8.54 ± 1.98^{c}	10.11 ± 2.99^{d}
Arithmetic mean diameter (cm)	5.75 ± 1.61^{a}	6.97 ± 2.13^{b}	9.14 ± 2.14^{c}	11.12 ± 2.62^{d}
Sphericity	0.78 ± 0.02^{a}	0.74 ± 0.04^{b}	0.81 ± 0.02^{a}	0.89 ± 0.04^{c}
% edible matter	66.45 ± 3.23^{a}	60.21 ± 3.12^{b}	58.48 ± 4.89^{b}	52.38 ± 6.21^{c}
% non-edible matter	32.41 ± 4.33^{a}	41.88 ± 4.23^{b}	41.15 ± 3.33^{b}	46.66 ± 2.75^{c}
Surface area (cm^2)	603.60 ± 145.40^{a}	804.90 ± 112.10^{b}	1007.90 ± 178.30^{c}	1331.60 ± 162.60^{d}

Values in the same rows followed by different superscript letters (a-d) are significant different (P<0.05)

In Table 4.1, the average diameters calculated by Geometric mean diameter (GM) and Arithmetic mean diameter (AM) is also mentioned. As the fruit maturity increased from stage 1 to 4 the average diameters increase for both hard and soft varieties ($P<0.05$). For hard variety, the GM and AM increased from 9.65cm to 15.37cm and 9.55cm to 15.49cm, as the stage changes from 1 to 4, respectively. For soft variety the GM and AM were recorded smaller than the hard variety, but similar type of trend can be observe in both the varieties. For soft variety, the GM and AM increased from 5.15cm to 10.11cm and 5.75cm to 11.12cm, as the stage changes from 1 to 4, respectively.

4.1.1.2 Sphericity

The sphericity of the jackfruit was highly influence by its stage of maturity for both the varieties, but for hard variety its influence was on higher side. For both the varieties the sphericity decreased with increase in stages ($P<0.05$). The fruit of hard variety was sphere in its initial stages i.e. 1 and 2 because sphericity values were 0.91 and 0.89, respectively, whereas it decreased to 0.83 at stage 4, thus the jackfruit became oblong. In case of soft variety the jackfruit was almost cylindrical in initial stages and retain oblong in stage 4. The sphericity values for soft variety in stage 1 and 4 were 0.78 and 0.89, respectively.

4.1.1.3 Percentage edible matter and percentage non edible matter

Tender Jackfruit at earlier stages had higher percentage of edible matter than later stage. Hence for stage 1, percentage edible matter for both hard and soft variety were 63.41 and 66.45, and it decreased by 12.36% and 21.17%, respectively, at stage 4 ($P<0.05$). The reason behind this could be the thickness of peel and amount of seeds (%age non edible matter) were lesser in initial stages and its increased with increase in maturity.

4.1.1.4 Surface area

From Table 4.2, it was clear that surface area is dependent on the maturity stage of fruit, because it based on linear dimension and linear dimension are the function of maturity stages was already discussed. For hard variety, surface area increased from $980.6\pm113.3cm^2$ to $1534.5\pm189.5cm^2$ and recorded asincrease of 56.48% as the stage changes from 1 to 4. On the other side, for soft variety, surface area increased from $603.6\pm145.4cm^2$ to $1331.6\pm162.6cm^2$ and recorded asincrease of 120.6% as the stage changes from 1 to 4.

4.1.2 Proximate properties

4.1.2.1 Moisture content (w.b.)

In Table 4.2, the mean moisture content (MC) (w.b.) at different stages were mentioned. As the fruit maturity increased from stage 1 to 4 the mean moisture content decreased for both hard and soft varieties ($P<0.05$). For hard variety, the values of MC (w.b.) decreased from 89.5 % to 74.4 % as the stage changed from 1 to 4, respectively. For soft variety MC (w.b.) recorded higher than the hard variety. For soft variety, the MC (w.b.) decreased from 92.8 % to 78.8 %, as the stage changes from 1 to 4, respectively.

Table 4. 2: Proximate properties of two varieties of tender jackfruit at different stages of maturity.

Properties	Hard variety			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Moisture Content (%)	89.40 ± 4.60^{a}	84.20 ± 3.60^{b}	76.10 ± 6.20^{c}	74.40 ± 3.30^{c}
Ash Content (%)	0.98 ± 0.02^{a}	0.98 ± 0.03^{ab}	0.99 ± 0.02^{bc}	0.99 ± 0.04^{c}
Total Solids (%)	0.12 ± 0.03^{a}	0.14 ± 0.02^{b}	0.15 ± 0.02^{c}	0.15 ± 0.02^{c}
pH	6.08 ± 0.04^{a}	6.21 ± 0.02^{b}	6.13 ± 0.03^{c}	6.11 ± 0.02^{ac}
TSS(°Brix)	1.50 ± 0.02^{a}	2.40 ± 0.04^{b}	2.80 ± 0.02^{b}	5.10 ± 0.03^{c}
TDS (ppm)	1.22 ± 0.18^{a}	1.73 ± 0.32^{b}	1.96 ± 0.21^{c}	2.33 ± 0.58^{d}
Properties	**Soft variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Moisture Content (%)	92.80 ± 4.60^{a}	91.10 ± 3.60^{a}	84.90 ± 4.60^{b}	78.80 ± 5.60^{c}
Ash Content (%)	0.99 ± 0.05^{a}	0.99 ± 0.02^{a}	0.99 ± 0.03^{b}	0.99 ± 0.06^{b}
Total Solids (%)	0.18 ± 0.01^{a}	0.20 ± 0.01^{b}	0.22 ± 0.01^{c}	0.22 ± 0.01^{c}
pH	6.78 ± 0.02^{a}	6.06 ± 0.06^{b}	6.44 ± 0.05^{c}	6.56 ± 0.06^{ac}
TSS(°Brix)	2.70 ± 0.05^{a}	4.90 ± 0.07^{b}	6.30 ± 0.12^{c}	7.10 ± 0.05^{d}
TDS (ppm)	1.03 ± 0.26^{a}	1.11 ± 0.78^{a}	2.66 ± 0.41^{b}	2.53 ± 0.20^{b}

Values in the same rows followed by different superscript letters (a-d) are significant different ($P<0.05$)

4.1.2.2 Ash content, total solids and pH

From Table 4.2, the ash content, total solid content and pH of hard variety of jackfruit were not shown any significant deviation from its means ($P<0.05$). Similar type of trend was observed in soft variety of jackfruit as well. Although the values of ash content, total solids and pH are higher for soft variety than hard variety. The average values of ash content, total solids and pH throughout the stages for hard variety were 99.12±0.02%, 0.14±0.02, 6.13±0.03 and for soft variety were 99.12±0.02%, 0.20±0.01 and 6.44±0.05, respectively.

4.1.2.3 TSS and TDS

Tender jackfruit in its initial stages had loweramount of TSS and TDS than later stage. Hence for stage 1, TSS and TDS for both hard and soft variety were 1.5±0.02°brix, 1.22±0.18ppm, 2.7±0.05°brix and 1.03±0.26 ppm, hence it increased by 240%, 90.98%, 162.96% and 145.63% respectively at stage 4 ($P<0.05$).

4.1.3 Nutritional properties

In Table 4.3, the nutritional properties at different stages are mentioned. As the fruit maturity in hard variety increased from stage 1 to 4 the decrease in Vitamin A and C was measured from 39.4±3.6 to 27.0±3.1IU/100g and 18.65±0.24 to 12.06±0.68mg/100g, respectively, ($P<0.05$). These properties were almost unchanged with stage of maturity from 1 to 4.

Whereas, carbohydrates, calcium, sodium, phosphorus, potassium, energy shown a significant ($P<0.05$) increase in quantities from 54.6±2.6 to 57.5±1.6g/100g, 1.46±0.43 to 43.6±0.93mg/100g, 26.1±2.5 to 22.8±1.6mg/100g, 254.4±2.5 to 412.6±4.9mg/100g and 159.1±11.4 to 444.8±39.6kJ/100g, respectively. Other properties like fat, fibre, protein and mineral content did not shown significant relation with change on stage of jackfruit. Whereas in case of soft variety of tender jackfruit the nutritional properties had shown similar type of trends. As the fruit maturity in soft variety of tender jackfruit increased from stage 1 to 4 the decrease in Vitamin A and C were found and measured as, 44.40±2.60 to 22.50±0.30IU/100g and 12.12±1.12 to 7.04±1.10mg/100g, respectively, ($P<0.05$). Whereas carbohydrates, calcium, sodium, phosphorus, potassium, energy shown a significant ($P<0.05$) increase in quantities from 19.60±0.5 to 25.80±0.30g/100g, 43.80±1.80 to 57.50±1.60mg/100g, 12.10±0.38 to 43.60±0.93mg/100g, 2.30±0.60 to 22.80±1.60mg/100g, 190.60±4.50 to 412.60±4.90mg/100g, 312.80±22.40 to 444.80±39.60kJ/100g respectively.

Table 4.3: Nutritional properties of two varieties of tender jackfruit at different stages of maturity (per 100 g of sample).

Nutrients	**Hard variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Protein (g)	2.10± 0.43 [a]	2.40± 0.64 [b]	2.40± 0.33 [b]	2.60± 0.78 [c]
Fat (g)	0.14 ± 0.03 [a]	0.09 ± 0.07 [a]	0.30± 0.21 [b]	0.61 ± 0.12 [c]
Carbohydrate (g)	12.40± 0.90 [a]	12.50± 0.90 [a]	14.20± 0.80 [b]	16.50± 0.30 [c]
Fibre (g)	4.40± 0.20 [ac]	3.10± 0.50 [b]	4.10± 0.10 [cd]	3.90± 0.50 [d]
Vitamin A (IU)	39.40± 3.60 [a]	31.20± 4.30 [b]	28.60± 2.70 [bc]	27.00± 3.10 [c]
Vitamin C (mg)	18.65 ± 0.24 [a]	16.98 ± 0.36 [b]	13.62 ± 0.48 [c]	12.06 ± 0.68 [d]
Total minerals (g)	0.80 [a]	0.90 [b]	0.90 [b]	0.90 [b]
Calcium (mg)	54.60± 2.60 [a]	63.40± 3.00 [b]	68.60± 2.20 [c]	75.80 ± 1.40 [d]
Sodium (mg)	1.46 ± 0.43 [a]	8.43 ± 0.32 [b]	22.67 ± 0.81 [c]	26.10± 0.87 [d]
Phosphorus (mg)	26.10± 2.50 [a]	35.20± 1.60 [b]	48.60± 1.50 [c]	50.20± 2.20 [c]
Potassium (mg)	254.40± 2.50 [a]	226.60± 4.10 [b]	294.00± 3.10 [c]	303.00± 1.40 [c]
Energy (kJ)	159.10± 11.40 [a]	183.40± 19.50 [b]	198.50± 5.30 [c]	212.40± 11.90 [d]
Nutrients	**Soft variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Protein (g)	1.10± 0.56 [a]	1.30± 0.44 [a]	1.70± 0.21 [b]	1.90± 0.88 [b]
Fat (g)	0.92 ± 0.22 [a]	1.60 ± 0.42 [b]	0.36 ± 0.14 [c]	0.44 ± 0.11 [d]
Carbohydrate (g)	19.60± 0.50 [a]	18.30± 0.70 [a]	22.50± 0.50 [b]	25.80± 0.30 [c]
Fibre (g)	2.10± 0.10 [a]	2.10± 0.10 [a]	2.30± 0.20 [b]	2.30± 0.10 [b]
Vitamin A (IU)	44.40± 2.60 [a]	32.80± 1.60 [b]	24.40± 1.70 [c]	22.50± 2.40 [c]
Vitamin C (mg)	12.12 ±1.22 [a]	9.84 ±1.32 [b]	7.78 ±0.98 [c]	7.04 ± 1.10 [c]
Total minerals (g)	0.70 [a]	0.60 [b]	0.80 [c]	0.60 [b]
Calcium (mg)	43.80± 1.80 [a]	49.60± 1.40 [b]	52.10± 1.20 [c]	57.50± 1.60 [d]
Sodium (mg)	12.10± 0.38 [a]	19.40± 0.86 [b]	44.30 ± 0.45 [c]	43.60± 0.93 [c]
Phosphorus (mg)	2.30± 0.60 [a]	14.30± 1.80 [b]	19.70± 1.60 [c]	22.80 ± 1.60 [d]
Potassium (mg)	190.60± 4.50 [a]	220.80± 3.60 [b]	288.60± 7.50 [c]	412.60± 4.90 [d]
Energy (kJ)	312.80± 22.40 [a]	244.80± 19.90 [b]	387.00± 31.80 [c]	444.80± 39.60 [d]

Values in the same rows followed by different superscript letters (a-d) are significantly different ($P<0.05$)

4.1.4 Textural properties

Textural properties of the tender jackfruit were found out with the help of texture analyser by performing TPA (textural profile analysis) on the sample from all 4 stages of both varieties of tender jackfruit. Hardness for both hard and soft varieties was increased from 9.80±1.20 to 14.90±1.10N and 5.10±1.30 to 8.40±0.80N, respectively. With hardness the other two properties such as fracturability and springiness also increased with stage of maturity from 0.38±1.03 to 11.09±1.16N and 15.85±0.52 to 19.49±0.36mm for hard variety and 0.48±0.13 to 6.45±0.56N and 16.51±0.27 to 27.77±0.15mm for soft variety, respectively. The properties like cohesiveness and gumminess decreased with maturity.

The values for cohesiveness and gumminess for hard and soft varieties of jackfruit decreased from 0.93±0.04 to 0.21±0.03; 1.49±0.33 to 0.76±0.29 N and 5.15±0.32 to 0.51±0.61N; 19.53±0.66 to 5.78±0.78N, respectively. The other two properties, adhesiveness and chewiness are independent of stages of maturity for both the varieties (Table 4.4).

Table 4. 4**:** Textural properties of two varieties of tender jackfruit at different stages of maturity.

Properties	Hard variety			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Hardness (N)	9.80± 1.20 ^{a}	10.20± 1.60 ^{a}	13.70± 0.90 ^{b}	14.90± 1.10 ^{b}
Adhesiveness (J)	0.07 ± 0.01 ^{a}	0.06 ± 0.01 ^{ab}	0.04 ± 0.01 ^{c}	0.06 ± 0.01 ^{ab}
Fracturability (N)	0.38 ± 1.03 ^{a}	4.66 ± 1.11 ^{b}	8.84 ± 0.72 ^{c}	11.09 ± 1.16 ^{d}
Cohesiveness	0.93 ± 0.04 ^{a}	0.62 ± 0.02 ^{b}	0.49 ± 0.02 ^{c}	0.21 ± 0.03 ^{d}
Springiness (mm)	15.85 ± 0.52 ^{a}	15.94 ± 0.44 ^{a}	18.82 ± 0.41 ^{b}	19.49 ± 0.36 ^{c}
Chewiness (J)	0.14 ± 0.02 ^{a}	0.11 ± 0.02 ^{b}	0.17 ± 0.01 ^{c}	0.13 ± 0.02 ^{ab}
Gumminess (N)	5.15 ± 0.32 ^{a}	4.11 ± 0.28 ^{b}	1.15 ± 0.61 ^{c}	0.51 ± 0.61 ^{d}
Properties	**Soft variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Hardness (N)	5.10± 1.30 ^{a}	6.70± 0.70 ^{b}	7.30± 0.80 ^{c}	8.40± 0.80 ^{d}
Adhesiveness (J)	0.02 ± 0.01 ^{a}	0.02 ± 0.01 ^{a}	0.04 ± 0.01 ^{b}	0.05 ± 0.01 ^{c}
Fracturability (N)	0.48 ± 0.13 ^{a}	3.69 ± 0.41 ^{b}	5.17 ± 0.44 ^{c}	6.45 ± 0.56 ^{d}
Cohesiveness	1.49 ± 0.33 ^{a}	0.84 ± 0.10 ^{b}	0.73 ± 0.09 ^{c}	0.76 ± 0.29 ^{c}
Springiness (mm)	16.51 ± 0.27 ^{a}	20.16 ± 0.53 ^{b}	24.88 ± 0.42 ^{c}	27.77 ± 0.15 ^{d}
Chewiness (J)	0.17 ± 0.02 ^{a}	0.15 ± 0.02 ^{b}	0.12 ± 0.02 ^{c}	0.17 ± 0.01 ^{a}
Gumminess (N)	19.53 ± 0.66 ^{a}	15.98 ± 0.82 ^{b}	9.13 ± 0.79 ^{c}	5.78 ± 0.78 ^{d}

Values in the same rows followed by different superscript letters (a-d) are significant different (P<0.05)

4.1.5 Colour

From the colour measurement (Table 4.5) it was found that the colour of tender jackfruit for both the varieties was bright green but the soft variety of jackfruit was having more eye catching colour at stage 1 and 2 of maturity (a* values is above 4). As the maturity stages increasedthe colour of both the varieties of jackfruit became dull and tends to pale yellowish since b* values decreased. The significant changes (P<0.05) in colour was found in both the varieties of jackfruit. From the colour values it was adviced that it is preferable to sell the jackfruit during stage 1 and 2 because the appearance at stage 1 and 2 were scored more in sensory evaluation.

Table 4. 5: Colour properties of two varieties of tender jackfruit at different stages of maturity.

Properties	**Hard variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
L*	24.49 ± 2.43 [a]	32.38 ± 3.35 [b]	34.49 ± 1.41[c]	38.65 ± 2.99 [d]
a*	2.33 ± 0.35 [a]	1.12 ± 0.41 [b]	0.33 ± 0.31 [c]	0.11 ± 0.31 [d]
b*	19.88 ± 0.74 [a]	16.39 ± 3.76 [b]	14.83 ± 0.34 [c]	10.34 ± 2.13 [d]
Properties	**Soft variety**			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
L*	35.55 ± 2.35 [a]	41.49 ± 4.33 [b]	44.49 ± 2.33 [c]	52.31 ± 1.88 [d]
a*	4.97 ± 0.99 [a]	4.69 ± 0.71 [a]	3.33 ± 1.33 [b]	1.12 ± 0.41 [a]
b*	23.12 ± 2.13 [a]	20.14 ± 4.10 [a]	17.23 ± 1.94 [c]	16.39 ± 2.86 [c]

Values in the same rows followed by different superscript letters (a-d) are significant different (P<0.05)

4.2 Controlling the browning of fresh-cut tender jackfruit[2]

The experiments were conducted and optimization was done by using response surface methodology (RSM), where the $CaCl_2$, citric acid and treatment time were independent variables and colour change (ΔE), browning index (BI), firmness and overall acceptability (OAA) were the dependent variables after the treatment of the tender jackfruit slices were kept for 3 days in refrigerator at 4 to 8°C. The experiments were performed in different combinations of independent variables as shown in Table 4.6 and 4.7.

Table 4. 6: Independent Variables and their levels

Factor	Name	Unit	Low Actual	High Actual	Low Coded	High Coded	Mean
A	$CaCl_2$	%	2.00	5.00	-1.00	1.00	3.50
B	Citric acid	%	1.00	2.50	-1.00	1.00	1.75
C	Time	min	3.00	10.00	-1.00	1.00	6.50

From the analysis of variances it was observed that all the dependent variables had significant sum of squares (p>0.01). There is good fit for model because of high R^2 value (>0.9). Lastly it was seen that the polynomial model had high goodness of fit.

[2]This work has been published as Rana, S.S., Pradhan, R.C., & Mishra S. (2018). Optimization of chemical treatment on fresh cut tender jackfruit slice for preservation of browning by using response surface methodology. *International food research journal*, 196-203. *(Scopus indexed)*

Table 4. 7: Experimental data in central composite design (CCD)

Experiment Run	$CaCl_2$	Citric acid	Time	Firmness	BI	ΔE	OAA
1	5.00	1.00	10.00	1.78	0.11	21.80	6.31
2	3.50	3.01	6.50	0.69	0.17	3.55	8.11
3	5.00	1.00	3.00	4.63	0.08	13.56	4.84
4	2.00	1.00	3.00	6.57	0.03	9.97	5.62
5	3.50	1.75	6.50	3.59	0.09	2.65	6.55
6	3.50	1.75	6.50	3.86	0.08	2.66	6.63
7	3.50	1.75	6.50	4.17	0.08	2.62	6.36
8	2.00	2.50	3.00	2.93	0.07	13.10	5.38
9	5.00	2.50	10.00	1.17	0.29	20.62	7.09
10	2.00	1.00	10.00	1.63	0.10	12.55	5.93
11	5.00	2.50	3.00	1.77	0.08	12.55	6.01
12	3.50	1.75	6.50	3.85	0.08	2.61	6.40
13	3.50	0.49	6.50	2.53	0.09	5.49	7.63
14	0.98	1.75	6.50	0.74	0.57	12.09	4.66
15	3.50	1.75	12.39	4.59	0.12	0.93	7.82
16	3.50	1.75	6.50	2.91	0.09	2.58	6.44
17	2.00	2.50	10.00	1.51	0.07	9.91	4.32
18	3.50	1.75	0.61	0.91	0.19	2.44	8.23
19	6.02	1.75	6.50	2.20	0.09	13.78	5.66
20	3.50	1.75	6.50	3.56	0.09	2.66	6.48

$CaCl_2$ - Calcium chloride; BI - Browning index; ΔE - Change in colour; OAA - Overall acceptability

4.2.1 Influence on firmness

According to Rico *et. al.,* (2007) texture is an important entity in determining the freshness of minimally processed fruits and vegetables. The firmness response to the independent variables has been shown in Figure 4.1. There was variation in the firmness of jackfruit slices of different treatments/ experiments run. The range for firmness was 0.69N to 4.59N Out of all the experiment combination the experiment run 15 was shown the maximum firmness value whereas the minimum value for firmness was 0.69N for experiment run 2.

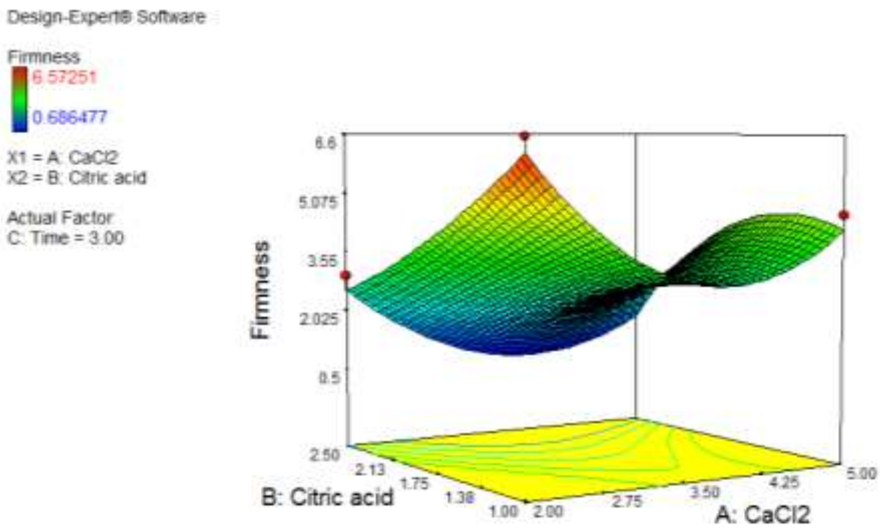

Figure 4.1: 3D surface curve for the effect of $CaCl_2$ concentrations and Citric acid concentration on firmness in minimally processed tender jackfruit slices

From the results it could be concluded that the firmness increased as the concentration of $CaCl_2$ and the treatment time was increased. The effect of $CaCl_2$ on the firmness was positive and it might be justified with the greater values for linear and quadric terms (β_1, β_{11}) of $CaCl_2$. A similar, significantly positive effect on firmness of tender jackfruit slices was shown by the concentration of citric acid and treatment time because of the greater values of their linear and quadric terms i.e. β_2, β_{22}, β_3 and β_{33}, respectively. There was the good fit for the quadric model with the data because of higher R^2 (0.97) value. It was stated that, the texture change in the minimal processed also influence enzymatic and non-enzymatic processes at certain level (Van Buren *et. al.*, 1979.) which also influences the sensory attributes of the minimal processed samples (Saxena *et. al.*, 2012.). According to Verala *et. al.*, (2007) keeping the minimal processed apple slices in calcium salt based solution for a while, resulted in prevention in solubilisation of pectin and maintained its sensory characteristics and texture. The benefits from the treatments were positive towards the better textural quality and prevention from microbial growth as well. The relationship between independent and dependent variables can be described by the following multiple regression equation.

$$\text{Firmness (N)} = 0.36+0.43A-0.55B+1.09C+0.36AC+0.72BC-0.58A^2-0.53B^2-0.12C^2-0.84C^2A-2.32B^2C-0.35BC^2 \quad \ldots 4.1$$

Where,

A= $CaCl_2$ concentration, (%)

B= Citric acid concentration, (%)

C= treatment time, min

4.2.2 Influence on the browning index (BI)

Koukounaras *et. al.,* (2008) reported in their study that browning is the important factor which remarkably influences the shelf life and marketing of minimal processed products. The Figure 4.2 shows the response of browning index to independent variables. The browning index varies from 0.035 to 4.595 for various combinations of treatments. From the all the treatment the experiment run 15 and experiment run 4 are having the maximum and minimum values for browning index respectively. As one factor the increase in concentration of $CaCl_2$ and treatment time resulted in significant decrease in browning index values of treatments. The interaction effect of concentration of citric acid and $CaCl_2$ at browning index values was highly influencing at higher concentration of citric acid and $CaCl_2$ for longer treatment time resulted in lower browning index (P>0.05). The effect of $CaCl_2$ on the browning index was negative and it might be justified with the values for linear and quadric terms (β_1, β_{11}) of concentration of $CaCl_2$. The linear terms citric acid was resulted in non-significant effect (P>0.05). The interaction effect between the concentration of $CaCl_2$ and concentration of citric acid influence the response significantly (P>0.05). There was good fit for the quadric model with the data because of higher R^2 (0.94) value. Oxidative browning been reported as very influencing parameter for shelf life of minimally processed fruit and vegetables (Sexena *et. al.,* 2012). Cocci*et. al.,* (2006) have been reported the positive effect of citric acid to minimize the browning index and extension of shelf life of minimal processed fruits. The multiple regression equation showed the final reduced model fitted for describing the relationship between the independent and (dependent variable) browning index.

$$\text{Browning Index (BI)} = 0.09-0.14A+0.02B-0.02C+0.02AB+0.02AC+0.01BC +0.06A^2+0.03ABC+0.06A^2C+0.18AB^2 \quad \ldots 4.2$$

Where,

A= $CaCl_2$ concentration (%)

B= Citric acid concentration (%)

C= treatment time (min)

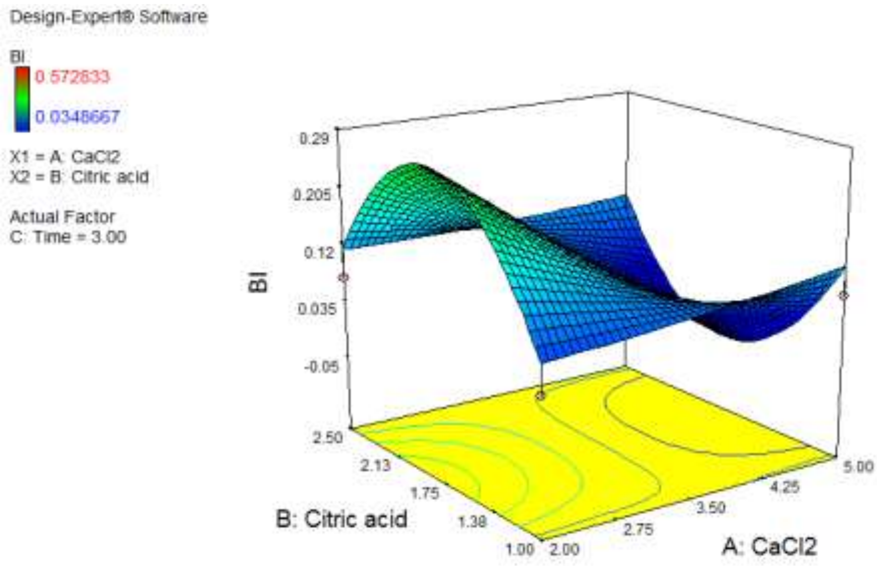

Figure 4.2: 3D surface curve for the effect of $CaCl_2$ concentrations and citric acid concentration on BI in minimally processed tender jackfruit slices

4.2.3 Influence on colour (ΔE)

Change in the colour of minimally processed tender jackfruit slices could properly described by colour change value (ΔE). The change in colour values with respectto the independent variables been presented in Figure 4.3. The maximum and minimum change in colour value varied from 0.93 to 21.80. Experiment run 1 reported the maximum value of change in colour, whereas experiment run 15 was reported with minimum value. The linear and quadratic terms of concentration of $CaCl_2$ (β_1, β_{11}), quadratic term of concentration of citric acid (β_{22}) and linear and quadratic terms of treatment time (β_3, β_{33}) were having negative effect on change in colour. The lower the value of change in colour, the better the colour quality of tender jackfruit, because it represents that there is least colour changes when compare to the fresh cut samples. The retention of colour was more in case at higher concentration of citric acid and longer treatment time. The coefficient of determination R^2 value was 0.94, which represent good fit of quadratic model with the experimental data. In case of minimal processed mangoes, the same kind of results were quoted by Robles-Sanchez *et. al.*, (2009). The retention of colour was because citric acid acts as radial scavenger. The relationship between independent and dependent variables could be described by the following multiple regression equation.

$$Colour=2.38+0.50A-0.58B-0.45C-0.34AB+2.11AC-0.74BC+5.26A^2+2.28B^2+1.28C^2$$
$$\cdot \quad +0.70ABC+0.36A^2B+2.41A^2C \qquad \ldots 4.3$$

Where,

A= $CaCl_2$ concentration (%)

B= Citric acid concentration (%)

C= treatment time (min)

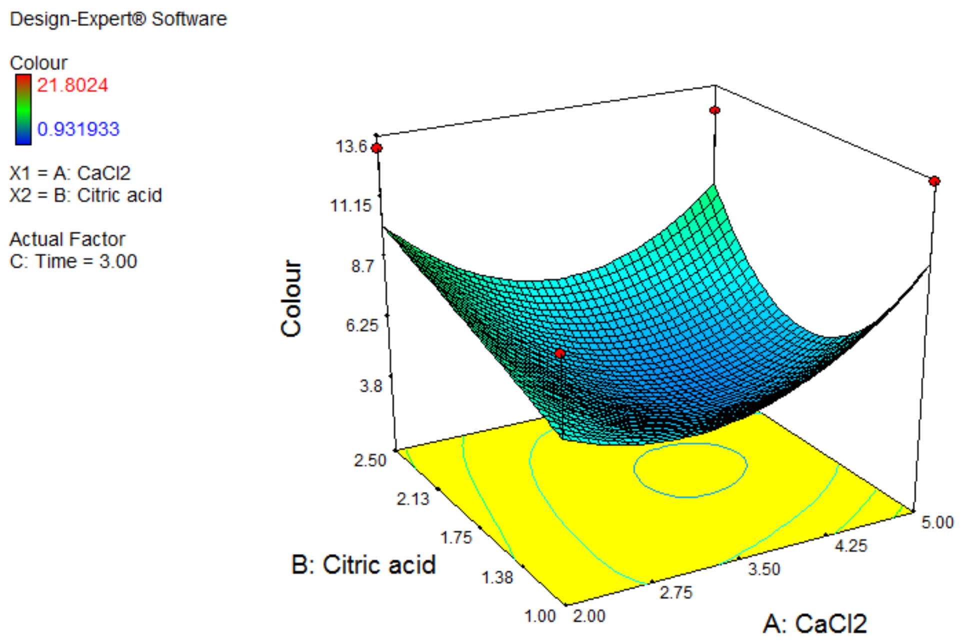

Figure 4.3: 3D surface curve for the effect of $CaCl_2$ concentrations and citric acid concentration on change in colour in minimally processed tender jackfruit slices

4.2.4 Influence on overall acceptability (OAA)

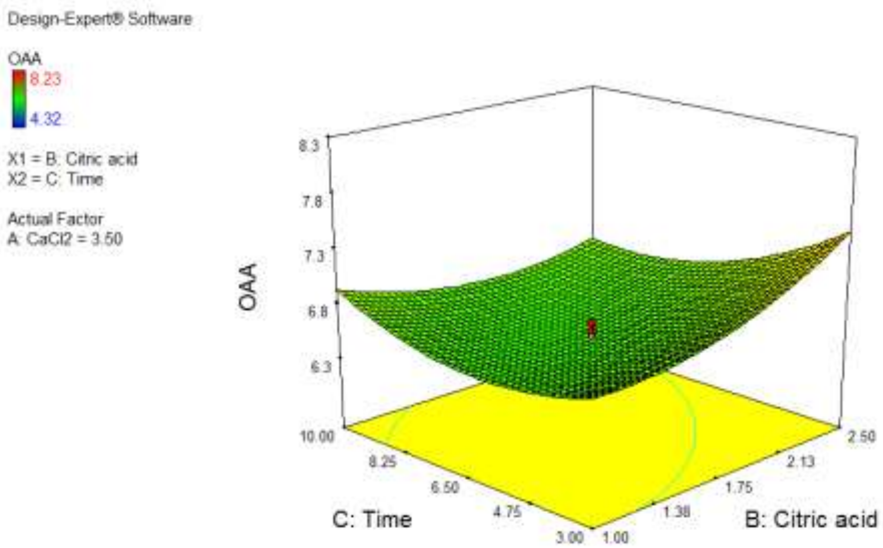

Figure 4. 4: 3D surface curve for the effect of $CaCl_2$ concentrations and Citric acid concentration on overall acceptability in minimally processed tender jackfruit slices

Figure. 4.4 shows the response of overall acceptability with respect to independent variables. The overall acceptability varies from 4.32 to 8.23 for various combinations of treatments. From all experiment, the experiment run 18 and experiment run 17 were having the maximum and minimum values for overall acceptability, respectively.

When consider as one factor the increase in concentration of $CaCl_2$ at certain level increased the overall acceptability and thus decreases further with increased in concentration of $CaCl_2$. Treatment time and citric acid concentration has no significant change in overall acceptability values of treatments. The interaction effect of concentration of citric acid and $CaCl_2$ on overall acceptability values was highly influenced and with increase in concentration of citric acid and $CaCl_2$ for longer treatment time resulted in higher browning index (P>0.05) at certain point and after that point the negative effect was observed. The effect of $CaCl_2$ on the overall acceptability was positive and it might be justified with the values for linear and quadric terms (β_1, β_{11}) of concentration of $CaCl_2$. The linear terms citric acid was resulted in non-significant effect (P>0.05).

The interaction effect between the concentration of $CaCl_2$ and concentration of citric acid influenced the response significantly (P>0.05). There was good fit for the quadric model with the data because of higher R^2 (0.91) value. The sensory values for the texture properties were found positively affected with the concentration of $CaCl_2$, and concentration of citric acid. Similar reports were quoted by Rocha and Morais (2003) in case of minimal processed apple slices. The multiple regression equation showed the final reduced model fitted for describing the relationship between the independent and overall acceptability.

$$OAA = 6.52+0.30A+0.14B-0.12C+0.48AB+0.41AC-0.22BC-0.75A^2+0.20B^2+0.26C^2 +0.12ABC-0.13A^2B+0.35A^2C+0.078AB^2 \quad \ldots 4.4$$

Where,

A= $CaCl_2$ concentration, (%)

B= Citric acid concentration (%)

C= treatment time (min)

4.2.5 Optimization

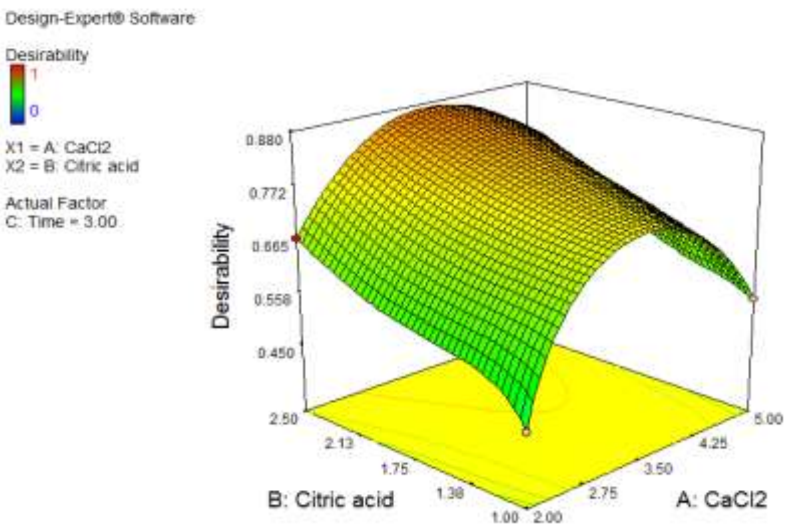

Figure 4. 5: 3D surface curve for the effect of $CaCl_2$ concentrations and Citric acid concentration on desirability in minimally processed tender jackfruit slices

To optimising the different treatments for minimal processing of fresh cut tender jackfruit the graphical and numerical optimising technique was used. The contour plots were reported that one factor effect and interactive effect of various independent variables on the dependent variables. Overlay contours and 3D plot of dependent were created for any given treatment by plotting between any two independent variables and keeping third independent variable as constant. The desirability plot of concentration of $CaCl_2$ and citric acid was drawn with treatment time at its minimum value. The constant term applied for the curve is treatment time at 3min (Figure 4.5).

The desirability curve was concave in nature. From the curve most desirable results was taken at highest citric acid concentration and concentration of $CaCl_2$ at centre points. The optimum range from the desirability curve and overlay plot were found to be 3.17% concentration of $CaCl_2$, 1.37 % concentration of citric acid and 6.78min treatment time. These parameters were resulted for graphical optimization. When optimization was done for maximum firmness, minimum change of colour (minimum ΔE), minimum browning index and maximum score for overall acceptability. The optimised treatment found was tabulated in Table 4.9. These optimised condition were helpful to find out the best treatment for optimised overall acceptability, which was very important factor to decide the popularity and acceptability of product in the market. Remaining experiments were carried out at given optimized conditions and the results compared with actual and predicted values from the model. From those results it could be concluded that second order polynomial model could be used to determining the quality of minimally processed tender jackfruit slices.

Table 4.8: Regression coefficients of fitted second-order polynomials model showing the relationship between independent and dependent variables

Coefficients	Firmness	BI	ΔE	OAA
β_0	3.63[a]	0.09[a]	2.38[a]	6.52[a]
		Linear		
β_1	0.43[a]	-0.14	0.50[a]	0.30[a]
β_2	-0.55[a]	0.02[a]	-0.56[a]	0.14[a]
β_3	1.09[a]	-0.02[a]	-0.45	-0.12[a]
		Interaction		
β_{12}	0.03[a]	0.02	-0.34	0.47
β_{13}	0.36	0.02[a]	2.11[a]	0.41[a]
β_{23}	0.72	0.01	-0.74[a]	-0.22
		Quadratic		
β_{11}	-0.58	0.06	5.26[a]	-0.75
β_{22}	-0.53[a]	-0.01[a]	2.28[a]	0.20[a]
β_{33}	-0.12[a]	0.00	1.28[a]	0.26[a]
R^2	0.97	0.94	0.94	0.91

[a] Significant at 5% level of significance; BI-Browning index; ΔE-Change in colour; OAA-Overall acceptability; β_0 – Regression co-efficient of fitted response at centre point; β_1,β_2 andβ_3 – Regression co-efficient for linear effect terms; β_{11},β_{22} andβ_{33} – Regression co-efficient for quadratic effect terms; β_{12},β_{23} andβ_{13} – Interaction effect

Table 4.9: Optimized independent variables and predicted and experimental values of dependent variables at optimum conditions (n=3)

Variables	Range	Optimum Conditions
$CaCl_2$(%)	2 to 5	3.17
Citric acid (%)	1 to 2.5	1.37
Time (min)	3 to 10	6.78
Response	**Predicted values by model**	**Experimental Values**
Firmness	3.74	3.50 ± 0.33
BI	0.10	0.99 ± 0.034
ΔE	3.21	2.99 ± 0.46
OAA*	6.45	6.89 ± 0.43

**n=10; $CaCl_2$ -Calcium chloride; BI-Browning index; ΔE -Change in colour; OAA-Overall acceptability*

Where independent parameters could be concentration of $CaCl_2$, concentration of citric acid and treatment time to the dependent variables such as browning index, overall acceptability, firmness and change in colour. Samples were treated with optimised treatment and kept in refrigerated conditions for storage study of 15 days. The treated samples were compared against untreated sample and it was found that untreated samples last only for 5 days whereas treated (with optimised treatment) samples were found good for consumption even on 15^{th} day of experiment.

4.3 Design and development of minimal processing machine for tender jackfruits[3]

One of the main objectives of this study was design and development of minimal processing (washing, peeling and cutting) machine for tender jackfruits, which can help rural people and also in similar types of processing plants. This section deals with the detailed design calculations and obtained results in the development of tender jackfruit minimal processing machine.

Minimal processing of tender jackfruit consists of operations like washing, peeling, cutting and treatment against browning of fruit. A jackfruit minimal processing machine required to perform all these operations. Washing can be done by cleaning the fruit under running water to remove mud or other undesirable material from its surface. Peeling is the process of removal of outer cover of tender jackfruit. Cutting is the operation to reduce the bigger sized product in small and convenience pieces. While in cutting of tender jackfruit, care was taken care so that the losses must be minimum. Operations like peeling and cutting of tender jackfruit lead to non-enzymatic browning of fruit, which can be controlled by chemical treatment.

A minimal processing machine for tender jackfruit is required to wash, peel, cut and process the tender jackfruit with minimum damage and losses. The ultimate objective of this study was to obtain design values of different components of the minimal processing machine to obtain maximum machine efficiency and minimum peeling damage and losses. The design values of the components and their adjustments causing the best performance

[3]**Patent**: An apparatus for peeling and cutting of tender jackfruit. **Inventors: Rana, S.S.**, Pradhan, R.C., Mishra, S. (2019). (Application No: 201931023023)

parameter were selected for the development and fabrication of final machine for minimal processing of tender jackfruit.

4.3.1 Pre-design experiment

The machine was developed as easy to adjust, easy to dismantle and easy to fabricate device for minimal processing machine for tender jackfruit. Before the design, some preliminary or basic experiments were conducted to determine some basic design parameter to enhance the design of the machine. These include the maximum length and diameter of fruit, shear and cutting forces required to peel the fruit, frictional properties of fruit, the surface area of fruit and other physical properties.

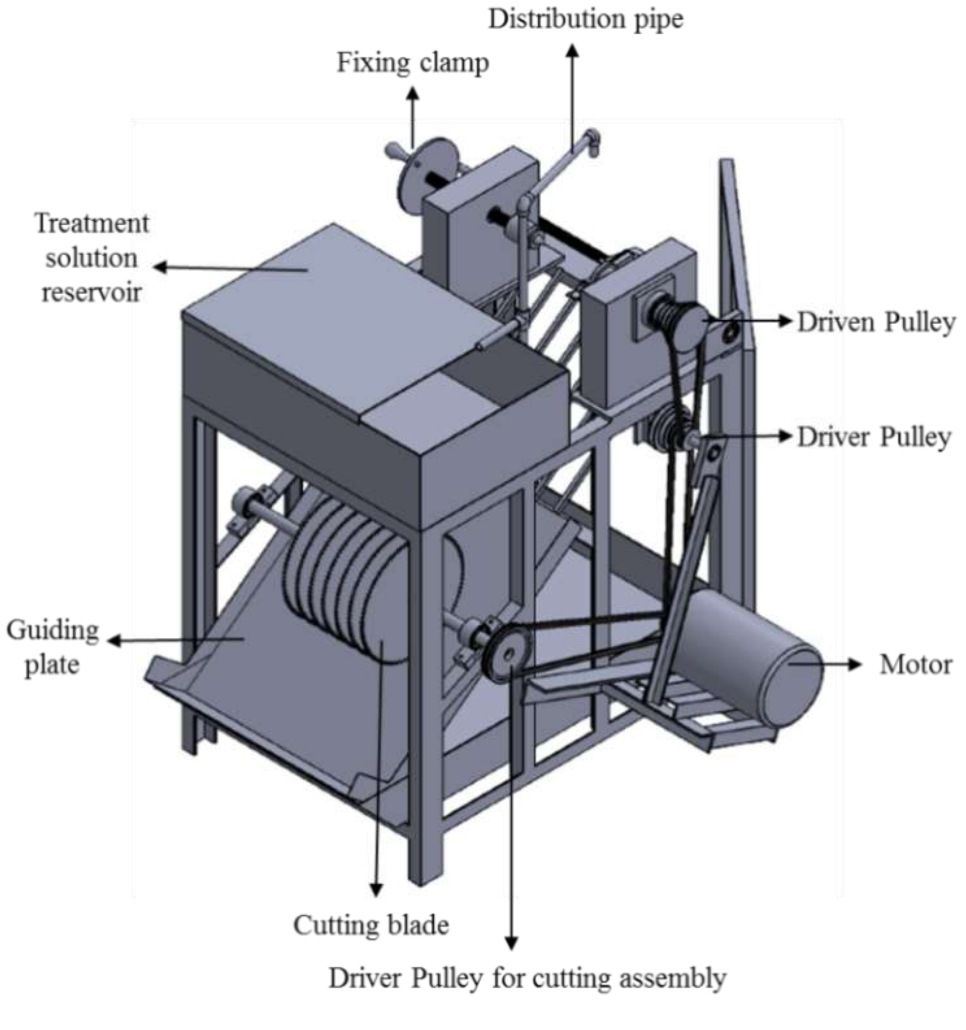

Figure 4.6(a)

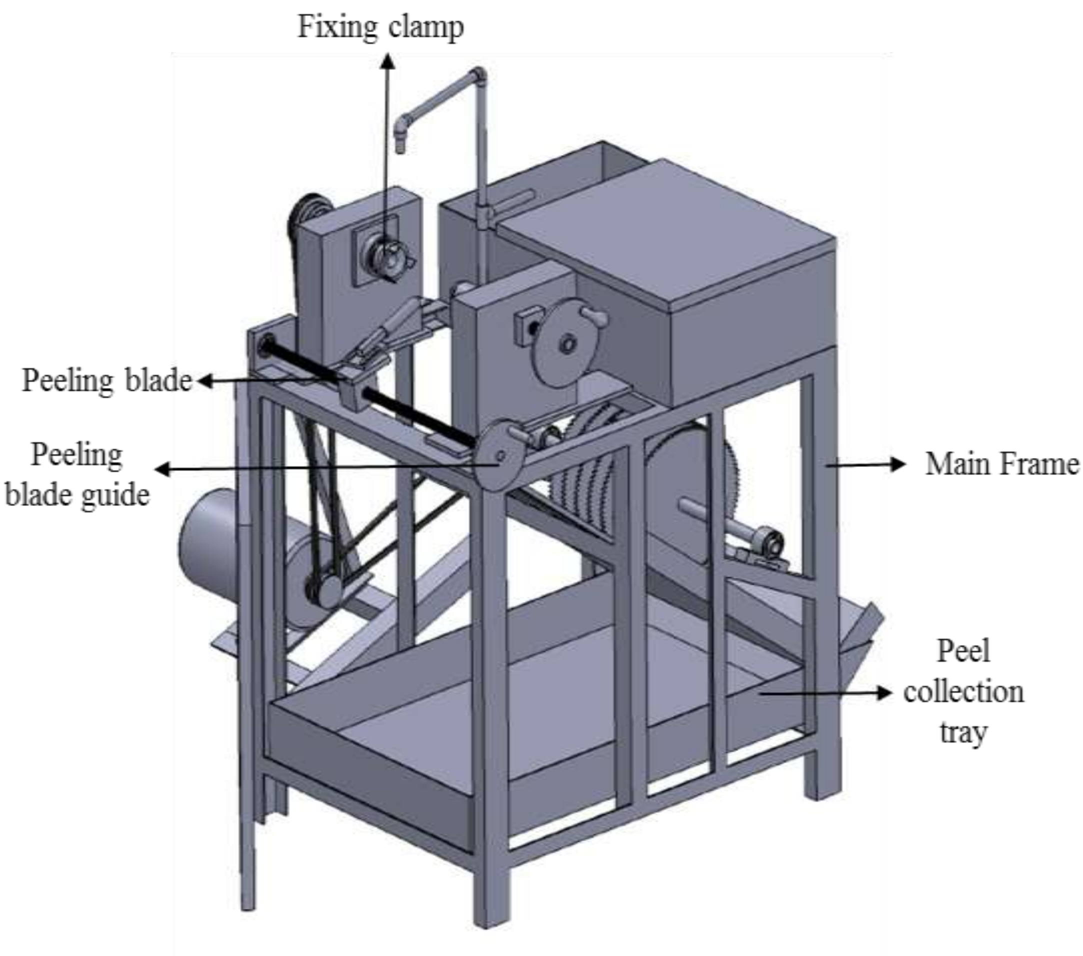

Figure 4.7(b)

Figure 4.8: Different componets of machines designed for minimal processing of tender jackfruit.

4.3.2 Design consideration

The machines of minimal processing for tender jackfruits includes compression, shearing and cutting. The developed machine utilizes the principle of shearing and cutting force. The following factors were considered in design and development of minimal processing machine for tender jackfruit.

i. Material of adequate strength and stability were used for fabrication of sample non-contact parts. (i.e. Mild steel)
ii. The machine was designed to have the maximum capacity of 25kg (9 to 12 jackfruits per hour) of tender jackfruit per hour so that it could be affordable for small scale industries.

iii. The materials that were available locally (plastic sheet; silicon pipes etc.) were used in the fabrication of the components.

Consideration was given to the cost of items and materials for fabrication with the ultimate aim of utilizing the cheapest available materials, yet satisfying all strength requirements.

4.3.3 Processing rate

It is the rate at which machine can process an input in unit time. It is generally expressed in kg/h.

$$Processing\ Rate = \frac{W_{avg} \times 60}{t_{avg}} \qquad \ldots 4.5$$

Where,

t_{avg} (min) is average time taken to completely peel a tender jackfruit

W_{avg} (kg) is average weight of unpeeled tender jackfruit.

In this case numerous tender jackfruits of different shapes and sizes were peeled and later cut in shape to facilitate packaging. Processing rate includes whole process peeling, blanching and cutting of tender jackfruit. The average weight (W_{avg} (kg)) of unpeeled tender jackfruit was 2.8 kg (approximate length 16.56±3.47 cm and diameter 10.97±2.97 cm) and average time taken for complete process of tender jackfruit was 6 min 24 seconds (6.4 min).

$$Processing\ rate = \frac{2.8\ \times 60}{6.4}$$

$$Processing\ rate = 26.25\ \ kg/h \qquad \ldots 4.6$$

To convert the processing rate from kg/h to number of jackfruits per hours, we use,

$$Processing\ rate = \frac{26.25\ \ kg/h}{2.8\ kg\ per\ jackfruit}$$

$$Processing\ rate = 9.375\ Jackfruits\ per\ hour \qquad \ldots 4.7$$

$$\cong 9\ Jackfruits\ per\ hour$$

Hence, 9 tender jackfruits can be processed in an hour from machine.

4.3.3.1 Machine-hour capacity

To determine the machine capacity, it is required to determine the machine-hour capacity. It can be expressed as running time of machine in a day.

Tender jackfruit processing machine can be worked for 8h/day. Hence, Machine-hour capacity for machine was 8 hours.

4.3.3.2 Machine capacity

It is defined as the amount of product can be processed by a machine in a day. It can be expressed in kg/day. The following equation can be used to determine the machine capacity.

$$Machine\ Capacity = Machine\ Hour\ Capacity\ \times Processing\ Rate \qquad \ldots 4.8$$

From above we can use the values of processing rate and machine-hour capacity to determine the value of machine capacity. The determined values for machine–hour capacity and processing rate were 26.25 kg/h and 8 h respectively.

$$Machine\ Capacity = 26.25\frac{kg}{h} \times 8h$$

$$Machine\ Capacity = 210kg\ per\ day$$

Machine capacity in terms of number of tender jackfruit peeled

$$Machine\ Capacity = \frac{210}{2.8}$$

$$Machine\ Capacity = 75\ tender\ jackfruits\ per\ day \qquad \ldots 4.9$$

4.3.4 Production-capacity utilization rate

Capacity-utilization rate is a measure of percentage of capacity of machine performance. The formula for capacity-utilization rate is actual output divided by the potential (maximum) output. The higher the percentage, the closer the machine is to performing at its full capacity.

$$Production\ Capacity\ Utilization\ Rate = \frac{Processing\ Rate}{Maximium\ Processing\ Rate} \times 100 \qquad \ldots 4.10$$

$$Production\ Capacity\ Utilization\ Rate = \frac{9}{9.375} \times 100$$

$$Production\ Capacity\ Utilization\ Rate = 96\ \% \qquad \ldots 4.11$$

The 96 % was high and it means the machine is performing to approximately to its maximum full capacity.

4.3.5 Design of machine components

4.3.5.1 Power requirement to peel

The average weight (W_{avg}), maximum length and average diameter of tender jackfruit were measured and considered as 2.8kg, 20cm and 16cm, respectively. From textural profile analysis (TPA) on the tender jackfruit (4 stages of 2 varieties) the mean force to peel the tender jackfruit was found to be 22.45N.

Assuming 20% more force for factor of safety and proper working of peeling blades

$$Total\ force, F = Factor\ of\ safety\ \times force\ on\ peeling\ blade \qquad \ldots 4.12$$

$$Total\ force, F = 1.2\ \times 22.45$$

$$Total\ force, F = 26.94\ N \qquad \ldots 4.13$$

Then, torque, T in Nm acting on the shaft will be,

$$T = F \times r \qquad \ldots 4.14$$

Where,

F is the total force, (N)

r is the radius of blade, (m)

$$T = 26.94 \times 0.16$$

$$T = 4.31\ Nm \qquad \ldots 4.15$$

Then, by using the above values, the power could be determined by using formula given below,

$$P = 2\pi NT \qquad \ldots 4.16$$

Where,

P is power (watt)

N is revolution per second (Diameter of motor pulley 10cm and diameter of peeler shaft pulley was 20cm, assuming motor pulley speed as 1500rpm, and using equation N1D1 =N2D2)

T is torque (Nm)

$$P = 2 \times \pi \times 12.5 \times 4.31$$

$$P = 338.335\, Watt$$

$$P = 0.45\, hp \qquad \dots 4.17$$

Consider the factor of safety for performance of machine as 2 to overcome the frictional losses, hence the power requirement for peeling of tender required by machine will be 0.9hp. However, the 0.9hp machine is not available in market therefore1hp machine will be stuffiest for peeling operation in machine. The consist of two sections i.e. peeling section and cutting section, which can be operated from same motor, therefore the power required to cut the tender jackfruit was measured separately and added to power required to peel the tender jackfruit to determine the overall power capacity of machine.

4.3.5.2 Design of shaft for peeling

Calculation of weight on shaft

$$Volume\ of\ holding\ clamps = \pi \times r^2 \times h \qquad \dots 4.18$$

Where,

r is the radius of shaft (cm)

h is the total length of shaft (cm)

$$= \pi \times 8^2 \times (6.5 + 9)$$

$$= 3116.46\, cm^3$$

$$Weight\ of\ holding\ clamps = \frac{3116.46 \times 7.8}{1000} \qquad \dots 4.19$$

(Specific gravity of MS piece is 7.8)

$$= 24.31 kg$$

Average weight of tender jackfruit = 2.8 kg

Total weight on peeling shaft = 24.31 + 2.8 = 27.11 kg

Assuming 30% marginal adjustment for welding materials, nut bolt, etc

Hence, net total weight on peeling shaft, W = 1.3 × 27.11 = 35.24 kg ≅ 35.24 kg … 4.20

Maximum bending movement, M

$$M = \frac{W \times l}{8} \quad \ldots 4.21$$

$$M = \frac{35.24 \times 82}{8}$$

$$= 361.22\ kg\ cm$$

$$= 35.42\ Nm$$

From above calculations, peeling shaft operated by a power motor, the equivalent torque can be determined by using following formula,

$$Equivalent\ Torque, T_e = \sqrt{(M^2 + T^2)} \quad \ldots 4.22$$

$$= \sqrt{(361.22^2 + 43.95^2)}$$

$$= 363.88\ kg\ cm$$

We also know that,

$$T_e = \frac{\pi}{16} \times d^3 \times F_s \quad \ldots 4.23$$

Where,

T_e is equivalent torque, (kg-cm)

d is diameter of shaft, (cm)

F_s is maximum shear stress (Let, maximum shear stress = 60 kg/cm^2)

$$363.88 = \frac{\pi}{16} \times d^3 \times 60 \quad \ldots 4.24$$

$$d = 3.13\ cm$$

Assuming factor of safety as 1.2, to overcome the unexpected frictions,

Therefore, d = 4cm.

Selecting SKF ball bearing 6208 with the following specification

Bore = 40mm

Outer diameter = 68mm

Width = 15mm

4.3.5.3 Selection of pulleys

Pulley for main shaft: 14cm

4.3.5.4 Power requirement to cut

The diameter of 1 blade be 35cm. Number of blades on shaft are 7 and gap between two blades are 4.2cm. Therefore, length covered by the blades was 25.2cm ($6 \times 4.2 = 25.2\ cm$).

The average weight of peeled Jackfruit, W_{avg} = 1.6 kg

Textural profile analysis was performed on the sample from all 4 stages of 2 varieties of tender jackfruit to determine the maximum force to cut the tender jackfruit, the mean force required to cut tender jackfruit 11.23N

Assuming 20% more force for factor of safety and smooth functioning of blades

$$Total\ force, F = Factor\ of\ safety\ \times no\ of\ blades\ \times force\ on\ each\ blades \quad \ldots 4.25$$

$$Total\ force, F = 1.2\ \times 7\ \times 11.23$$

$$Total\ force, F = 94.332\ N \quad \ldots 4.26$$

Then, torque, T in Nm acting on the shaft as,

$$T = F \times r \quad \ldots 4.27$$

Where,

F is the total force (N)

r is the radius of blade (m)

$$T = 94.332 \times 0.35$$

$$T = 33.016\ Nm \quad \ldots 4.28$$

Then, by using the above values, the power could be determined by using formula given below,

$$P = 2\pi NT \quad \dots 4.29$$

Where,

P is power (watt)

N is speed (rps)

T is torque (Nm)

$$P = 2 \times \pi \times 5 \times 33.016$$

$$P = 1037.228\ Watt$$

$$P = 1.39\ hp \quad \dots 4.30$$

Consider the factor of safety for smooth performance of machine as 1.2, hence the power requirement for peeling of tender required by machine will be 1.67hp. However, 1.67hp motor is not available in the market, hence 2hp motor can be used to cut the tender jackfruit.

4.3.5.5 Design of shaft for cutting

Calculation of weight on shaft

$$Volume\ of\ rotating\ blade = \pi \times r^2 \times h \quad \dots 4.31$$

Where,

r is the radius of shaft (cm)

h is the total length of shaft (cm)

$$= \pi \times 17.5^2 \times 0.3$$

$$= 288.63\ cm^3$$

$$Weight\ of\ 7\ rotating\ blades = \frac{7 \times 288.63 \times 7.8}{1000} \quad \dots 4.32$$

(Specific gravity of MS piece is 7.8)

$$= 15.76\ kg$$

Average weight of peeled jackfruit = 1.6 kg

Total weight on cutting shaft = 15.76 + 1.6 = 17.36 kg

Assuming 30% marginal adjustment for welding materials, nut bolt, etc.

Hence, Net total weight on cutting shaft, W = 1.3 × 17.36 = 22.57 kg ≅ 22.5 kg … 4.33

Maximum bending movement, M

$$M = \frac{W \times l}{8} \quad \text{…. 4.34}$$

$$M = \frac{22.5 \times 25.2}{8}$$

$$= 70.875\ kg\ cm$$

$$= 6.95\ Nm$$

From above calculations, cutting shaft operated by a power motor, the required power is 1037.228Watt and revolve at 300rpm (N = 5rps)

$$T = \frac{P}{2\pi N} \quad \text{… 4.35}$$

Where,

P is power (watt)

N is speed (rps)

T is torque (Nm)

$$T = \frac{1037.228}{2\pi \times 5}$$

$$= 33.02\ Nm$$

$$= 336.71\ kg\ cm$$

$$Equivalent\ Torque, T_e = \sqrt{(M^2 + T^2)} \quad \text{… 4.36}$$

$$= \sqrt{(70.875^2 + 336.71^2)}$$

$$= 344.088\ kg\ cm$$

We also know that,

$$T_e = \frac{\pi}{16} \times d^3 \times F_s \quad \text{… 4.37}$$

Where,

T_e is equivalent torque (kg-cm)

d is diameter of shaft, (cm)

F_s is maximum shear stress (Let, maximum shear stress = 60 kg/cm^2)

$$344.088 = \frac{\pi}{16} \times d^3 \times 60$$

$$d = 3.167\ cm$$

Assuming factor of safety as 1.2, therefore, d = 4cm.

Selecting SKF ball bearing 6208 with following specification

Bore = 40mm

Outer diameter = 68mm

Width = 15mm

4.3.5.6 Total power requirement for machine

The total power required for the machine is the sum of power required to peel the tender jackfruit and cut the tender jackfruit, because both the unit are running simultaneously (at same time). Hence, by using eqn 4.17 and eqn 4.30 the overall power required to run the machine can be determined.

From section 4.3.5.1 and section 4.3.5.4 the power required to peel the tender jackfruit was found 0.9hp and for cutting the jackfruit was found 1.67hp. Hence, the overall power required to peeling cum cutting was 2.57hp. However, 2.57hp motor is not available in market, therefore 3hp motor was used.

Table 4. 10: Specification of each machine component

Sl. No	Components	Materials Used	Specification
1.	Main frame	Cast Iron	Angled iron bar 0.03 x 0.003 x 0.002 m, 0-20^{o}inclination
2.	Fixing clamps	Stainless Steel (A-304)	
3.	Peeling blade	Stainless Steel (A-304)	
4.	Peeling blade guide	Stainless Steel (A-304)	
	Main shaft	Stainless Steel (A-304)	4 cm diameter
5.	Driver pulley	Stainless Steel(SS)	
6.	Driven pulley	Stainless Steel(SS)	
7.	Drive Mechanism		Belt: 0.015 m width, 0.002 m thick, N_1=1440 rpm, µ=4, N_2=360 rpm
8.	Treatment solution tank	Stainless Steel (A-304)	
9.	Distribution pipes	Stainless Steel (A-304)	
10.	Pump		
11.	Guide plate	Stainless Steel (A-304)	
12.	Cutting assembly		
	Main shaft	Stainless Steel (A-304)	4 cm diameter
13.	Drive mechanism		Belt: 0.015 m width, 0.002 m thick, N_1=1440 rpm, µ=4, N_2=360 rpm
14.	Collection tray	Stainless Steel(SS)	
15.	Motor		3 hp, 3 Phase, 50 Hz
16.	Bearing	Stainless Steel (SS)	Ball bearing and Gun metal bush bearing

4.4 Evaluation and optimization of machine performance

Whole jackfruit is fixed between the fixing clamps. The fruit starts rotating on its major axis as motor is switched on. The hard cover of the fruit is scratched against the sharp peeling blade. The specific shape of peeling blade helps to peel the skin from the surface. It also helps in minimising peeling loss of fruits because it can penetrate inside the fruit to a specific death. The blade dimensions are in such a way that only peel is removed and it should not penetrate inside the fruit. Forward and backward moments are provided in peeler guiding shaft so that the jackfruit peeled effortlessly.

The peeled fruit then enters into the cutting assembly with the help of guiding rods and guiding plate. The cutting assembly contains a main shaft and seven cutting blades mounted on it. The rotation of the main shaft and the cutting blades presses the peeled fruit on to the cutting blades. This creates enough centrifugal force to cut the peeled fruit.

After peeling and cutting the slices of fruits were fall into outlet trays with the help of guiding plate. Those slices were left at outlet for some time to drain the treatment solution over them. The treatment solution was sprinkled over the fruit during whole process of peeling and cutting. A separate assembly is assigned to sprinkle the treatment solution. This assembly is consisting of treatment solution holding tank, a submersible pump and pair of pipe system to pump the solution at desired rate to a certain place. The specifically designed shower sprinkler is provided to sprinkle the treatment solution.

The peel and used treatment solution is remained inside the machine. This can be removed later from waste collecting tray mounted under the peeling and cutting assembly. To facilitate smooth collection of waste and to drain treatment solution the provisions are provides in different components of machine.

4.4.1 Machine performance

The machine performance varies with changing the listed parameters (Table 4.11 and Table 4.12). To determine the optimized performance conditions, the following dependent and independent variables were considered within the mentioned ranges. The optimization was done separately for cutting assembly and peeling assembly because those are two different unit operations performed during the processing of jackfruit.

Table 4. 11: Parameters used for optimization of peeling performance

Sl. No	Variable/Parameter	Type	Range
1	Rotating speed (rpm)	Independent	65 to 280
2	Forwarding speed (rpm)	Independent	30 to 90
3	Peeling efficiency (%)	Dependent	Maximum
4	Peeling loss (%)	Dependent	Minimum
5	Peeling time (min)	Dependent	In the range

Table 4. 12: Parameters used for optimization of cutting performance

Sl. No	Variable/Parameter	Type	Range
1	Cutter Speed (rpm)	Independent	50 to 500
2	Cutting efficiency (%)	Dependent	Maximum
3	Cutting loss (%)	Dependent	Minimum

4.4.2 Effect of forwarding speed of peeler blade and rotating speed of peeler shaft on performance indices

Central Composite Design (CCD) was used in Design Expert (Ver. 7.0, Stat-Ease Inc., USA) for experiments to find the effect of rotating speed of peeler shaft and forward speed of peeler blade within the specified ranges. Thirteen (13) experiments were performed with five centre points (Table 4.13). Variation of performance indices such as peeling efficiency, peeling loss and peeling time of the machine was taken as response with respect to factors such as rotating speed and forward speed (Table 4.11). The peeling efficiency was in the range of 46.1 to 79.2% because some amount of peel was remained on the fruit. This was because of irregular shape of jackfruit, whereas oblong fruit gave higher peeling efficiency. Peeling loss ranged between a minimum of 13.19% to a maximum of 23.7%. The peeling time ranges from 3.8min to 7.23min. The performance indices vary in wide ranges due to the variation in physical properties of tender jackfruit. At higher rotating and forward speed, the fruits were not peeled properly. This resulted in more slippage during operation of the machine and caused lower peeling efficiency and high loss. Similar results were observed for very low rotating speed and high forward speed. There were unpeeled surfaces and more jackfruit was loss because of low speed. These results were in agreement with the findings for pineapple peeling (Adebayo *et. al*., 2014). The peeling efficiency of the peeler increased with the increase of speed at the initial stage and decreased later. The rotating speed and forwarding speed significantly ($P<0.001$) affected peeling efficiency and overall machine throughput (Asoiro and Udo, 2013).

Table 4. 13: Readings of experiments designed by Central Composite Design (CCD)

Sl. No	Rotating Speed (rpm)	Forward speed (rpm)	Peeling efficiency (%)	Peeling loss (%)	Peeling time (min)
1	173.5	60	78.68	15.01	5.19
2	173.5	17.5736	74.36	17.6	4.4
3	173.5	60	79.16	13.19	4.3
4	173.5	60	78.95	14.95	4.6
5	173.5	60	77.99	14.16	4.5
6	173.5	102.426	75.19	18.45	6.8
7	283	30	56.8	23.7	7.04
8	64	30	69.01	15.54	5.6
9	173.5	60	79.22	13.44	3.8
10	64	90	67.38	16.34	4.9
11	283	90	57.4	23.4	7.05
12	328.356	60	46.1	38.3	7.23
13	18.6436	60	67.12	18.47	5.3

4.4.2.1 Models generated from machine testing

The results of experiment conducted were fitted to a quadratic (second-order) polynomial models. Regression coefficients of the proposed models and statistical significance for each response were calculated to check the fitness of model. ANOVA of the results for all parameters such as peeling efficiency, peeling loss and peeling time suggested the significance of each response at $P< 0.05$. The quadratic/ polynomial models were suitable with R^2 and predicted R^2 higher than 0.9 for all the responses. The desirability and response surface graph (Figure 4.7 to 4.10) suggested the high sensitivity of the responses to independent factors (i.e. rotating speed and forward speed). The peeling efficiency have positive relations, and peeling loss and peeling time has a negative relation with the independent factors. The response surface models for various performance indices are as below in Equations below. The coefficient of variance for each of the models was less than 10 % and was having acceptable repeatability.

$$\text{Peeling efficiency} = 49.95 + (0.27 \times \text{Rotating speed}) + (0.34 \times \text{Forward speed}) + (1.7 \times 10^{-4} \times \text{Rotating speed} \times \text{Forward speed}) - (9.89 \times 10^{-4} \times \text{Rotating speed}^2) - (3.08 \times 10^{-3} \times \text{Forward speed}^2) \quad \ldots 4.38$$

$$\text{Peeling loss} = 24.27 - (0.12 \times \text{Rotating speed}) - (0.12 \times \text{Forward speed}) - (8.37 \times 10^{-5} \times \text{Rotating speed} \times \text{Forward speed}) + (5.21 \times 10^{-4} \times \text{Rotating speed}^2) + (1.19 \times 10^{-3} \times \text{Forward speed}^2) \quad \ldots 4.39$$

$$\text{Peeling time} = 7.95 - (0.02 \times \text{Rotating speed}) - (0.08 \times \text{Forward speed}) + (5.4 \times 10^{-5} \times \text{Rotating speed} \times \text{Forward speed}) + (7.9 \times 10^{-5} \times \text{Rotating speed}^2) + (6.83 \times 10^{-4} \times \text{Forward speed}^2 \quad \ldots 4.40$$

4.4.2.2 Optimized operating conditions

Optimum operating conditions for peeling of tender jackfruit were determined by response surface method (RSM) for the selected ranges of rotating speed of fruit and forward speed of peeling blade (Table 4.14). The RSM graph on performance indices such as peeling time, peeling efficiency and peeling loss are shown in Figure 4.8 to 4.11. The three-dimensional graph of peeling efficiency shows a plot that increase up-to a level and then again decreases as an effect of rotating speed and forward speed. Whereas, contour plot for peeling loss shows a decrease in the results up to a level and then increases with the effect of speed rotating speed and forward speed. Similar type of graph can be shown for peeling time. Desirability function of the CCD experimental design was used to get optimum operating parameters of the developed machine. The target for optimum machine parameters was to get maximum peeling efficiency with minimum peeling loss and peeling time. The desirability function analysis suggested optimum values of rotating speed and forward speed as 160.2rpm and 90rpm, respectively with a desirability value of 0.873. When the machine was operated at optimum conditions, the peeling efficiency and peeling loss and peeling time were 75.86±3.58%, 13.97±2.87%, and 5.5±0.5min, respectively. In practice, it is difficult to adopt the fractional values of optimized operating conditions. Hence, the suggested operating conditions such as rotating speed and forward speed are 160rpm and 90rpm respectively. Similar peeling efficiencies of 75% and 71% have been reported for pineapple and melon peelers, respectively (Adonis *et. al.,* 2016; Eyeowa *et. al.,* 2017).

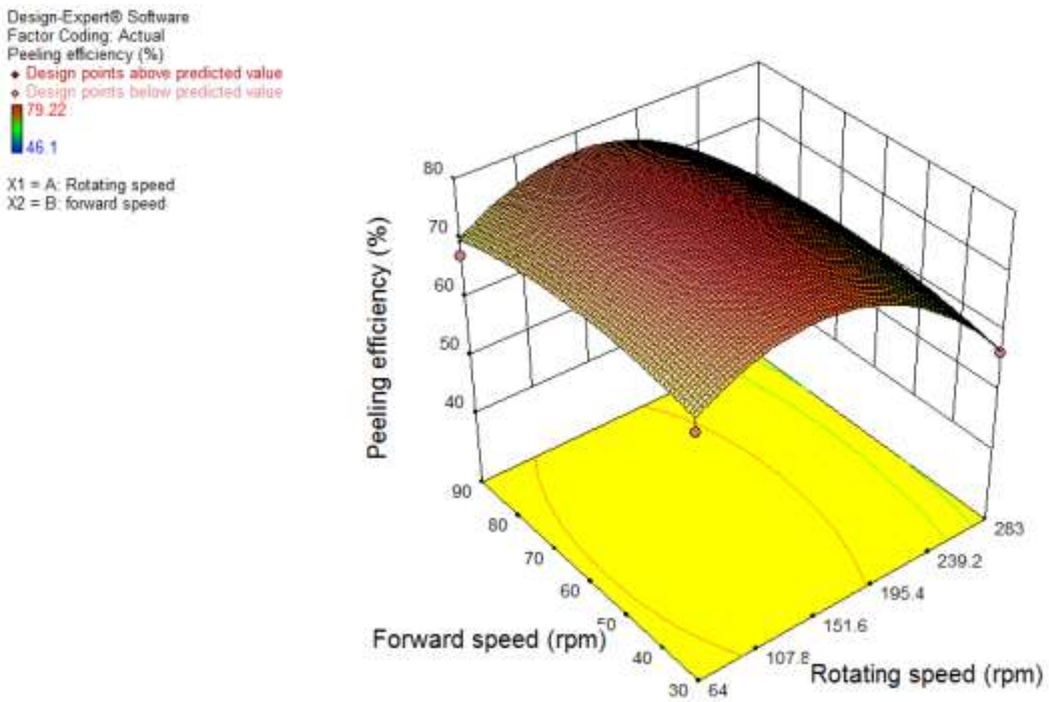

Figure 4. 9: 3D surface curve for the effect of rotating speed (rpm) of jackfruit and forward speed (rpm) of peeling blade on peeling efficiecncy

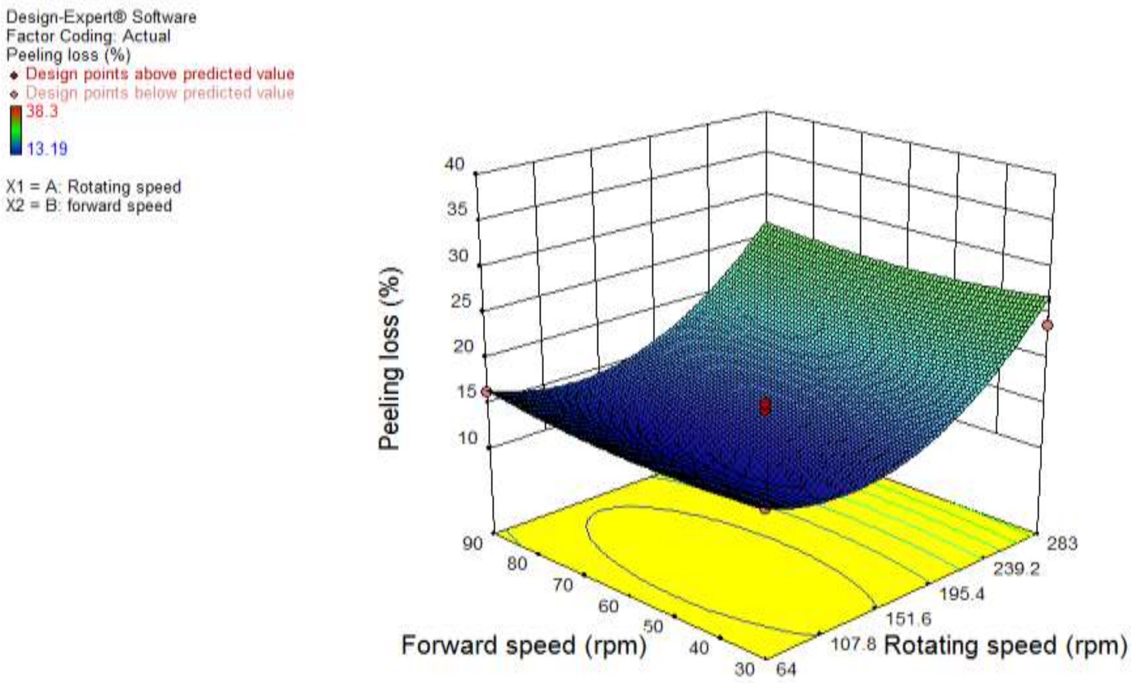

Figure 4. 10: 3D surface curve for the effect of rotating speed (rpm) of jackfruit and forward speed (rpm) of peeling blade on peeling loss.

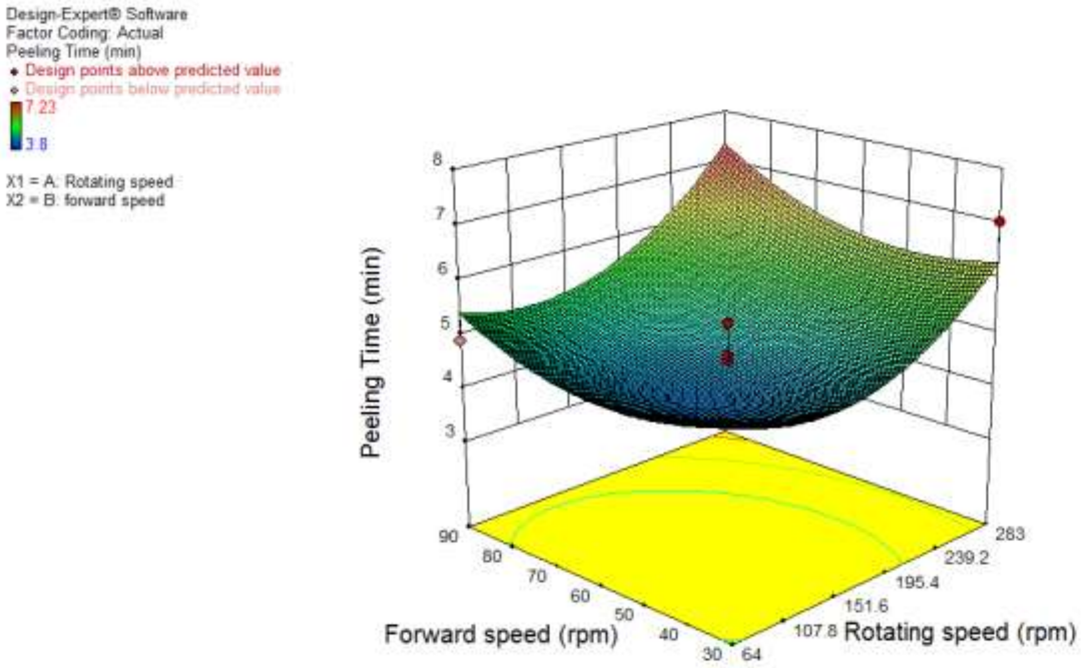

Figure 4. 11: 3D surface curve for the effect of rotating speed (rpm) of jackfruit and forward speed (rpm) of peeling blade on peeling time

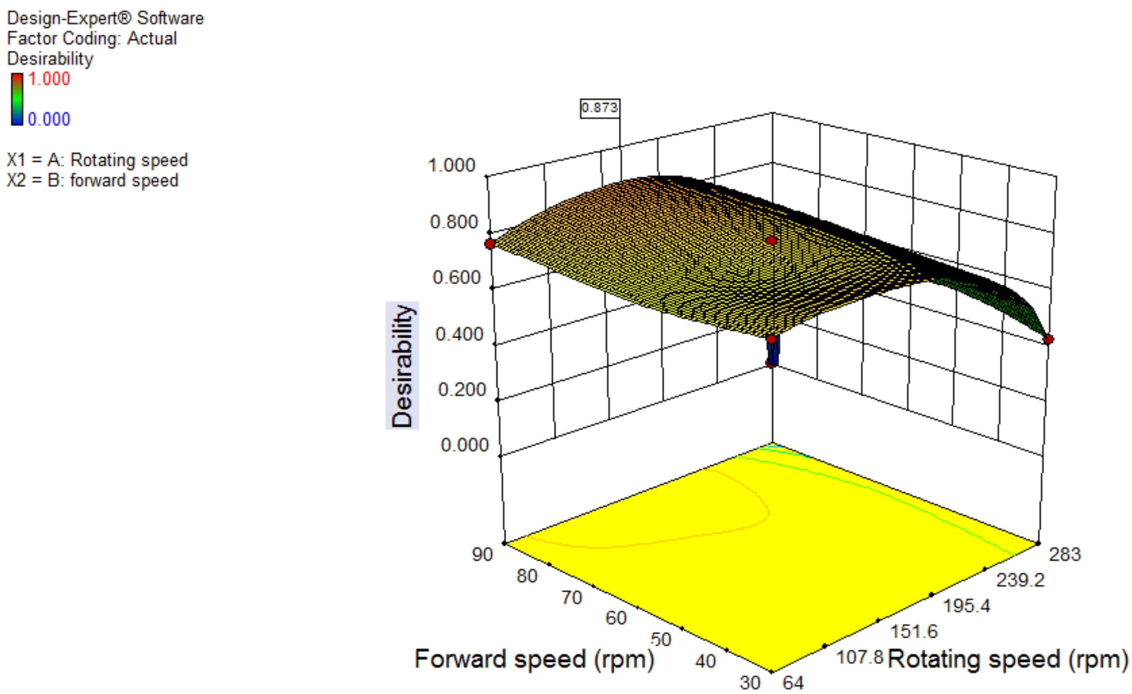

Figure 4. 12: 3D surface curve for the effect of rotating speed (rpm) of jackfruit and forward speed (rpm) of peeling blade on desirability

Table 4. 14: Optimized independent variables and predicted and experimental values of dependent variables at optimum conditions (n=3)

Variables	**Range**	**Optimum Conditions**
Rotating speed (rpm)	65 to 280	160.22
Forwarding speed (rpm)	30 to 90	90
Response	**Predicted values by model**	**Experimental Values**
Peeling efficiency (%)	76.59	75.86±3.58
Peeling loss (%)	14.9	13.97±2.87
Peeling time (min)	5.37	5.5±0.5

4.4.3 Effect of cutter speed on performance indices

One factor design (OFD) was used in Design Expert (Ver. 7.0, Stat-Ease Inc., USA) for experiments to find the effect of cutter speed within the specified ranges. Seven (7) experiments were performed with five centre points. Variation of performance indices such as cutting efficiency and cutting loss was taken as response with respect to factors such as cutter speed (Table 4.12). The cutting efficiency was in the range of 119.5 to 170.2%. Sometimes fruits slips away from the blades and sometimes there was side cut instead of proper horizontal cut. This might be because of improper falling of jackfruit on cutting blade or backward pull of fruit before going under the cutting blade. This can be overcome with little practice of the operator, which resulted in higher cutting efficiency. Cutting loss ranged between a minimum of 18.1% to a maximum of 30.9%. The performance indices vary in wide ranges due to the variation in sizes (especially diameter) of tender jackfruit. At higher cutter speed, the fruits were cut properly. The cuts were proper and sharp but, this also resulted in more slippage during operation of the machine and obtained lower cutting efficiency and high loss. Whereas at lower cutter speeds the cutter blades had tendency to stuck inside fruit and it needed to restart the machine to cut the tender jackfruit. The cuts at lower cutter speed are not proper and hence it results in lesser cutting efficiency and higher cutting loss. These results are in agreement with the findings for pineapple cutting (Adebayo *et al*. 2014). The cutting efficiency of the peeler increased with the increase of cutter speed at the initial stage and decreased later. The cutter speed significantly ($P < 0.05$) affected cutting efficiency, cutting loss and overall machine throughput (Asoiro and Udo, 2013).

Table 4.15: Readings of experiments designed by Single factor design

Sl. No	Cutting Speed (rpm)	Cutting efficiency (%)	Cutting loss (%)
1	500	140.93	26.76
2	50	119.36	30.16
3	275	156.67	22.14
4	162.5	148.52	25.12
5	387.5	169.75	18.34
6	500	140.08	27.31
7	50	119.11	29.86

4.4.3.1 Models generated from cutting blade

The results of experiment conducted were fitted to a quadratic (second-order) polynomial models. Regression coefficients of the proposed models and statistical significance for each response were calculated to check the fitness of model. ANOVA of the results for all parameters such as cutting efficiency and cutting loss suggested the significance of each response at $P<0.05$. The quadratic/ polynomial models were suitable with R^2 and predicted R^2 higher than 0.9 for all the responses. The desirability and response surface graph (Figure 4.12 to 4.14) suggested the high sensitivity of the responses to independent factor (i.e. cutter speed). The cutting efficiency have positive relations, and cutting loss has a negative relation with the independent factors. The response surface models for various performance indices were shown below in equation. The coefficient of variance for each of the models was less than 10 % and was having acceptable repeatability.

$$\text{Cutting efficiency} = 76.11 + (1.17 \times \text{cutter speed}) - (7.19 \times 10^{-3} \times \text{cutter speed}^2) \quad \ldots 4.41$$

$$\text{Cutting loss} = 37.12 - (0.198 \times \text{cutter speed}) - (1.297 \times 10^{-3} \times \text{cutter speed}^2) \quad \ldots 4.42$$

4.4.3.2 Optimized operating conditions for cutter blade

Optimum operating conditions for cutting of tender jackfruit were determined by response surface method (RSM) for the selected ranges of cutter speed (Table 4.16). The target for optimum cutting parameter was to get maximum cutting efficiency with minimum cutting loss. The desirability function analysis suggested optimum values of cutting speed as 398.75rpm. When the machine was operated at optimum conditions, the cutting efficiency and cutting loss were 170.14±4.43% and 18.29±3.13%, respectively. In practice, it is difficult to adopt the fractional values of optimized operating conditions. Hence, the suggested operating conditions such as cutter speed as 400rpm.

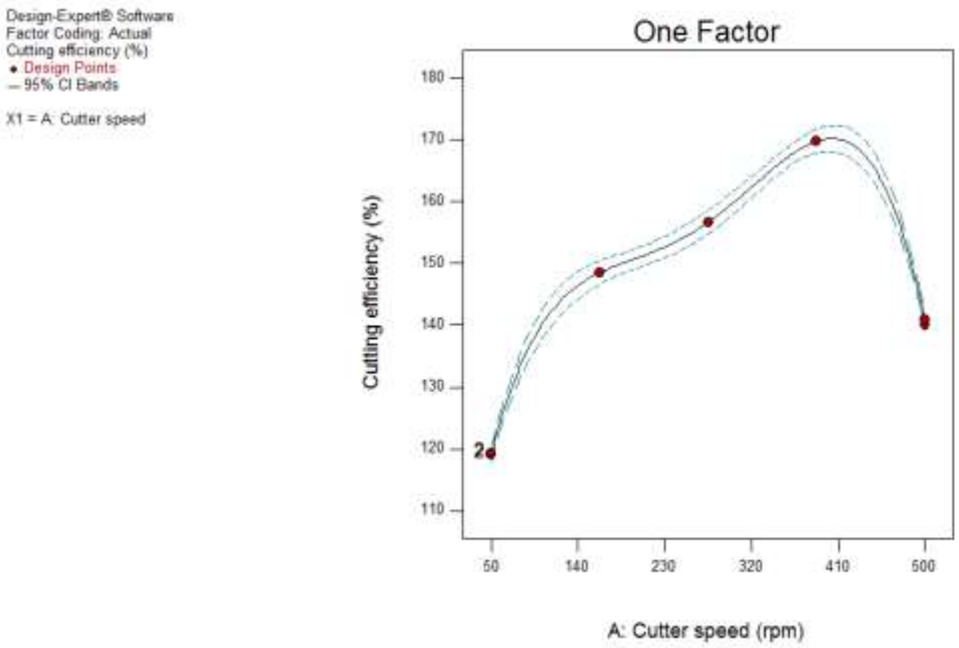

Figure 4. 13: Surface curve between cutting efficiency (%)of machine and cutter speed (rpm) of cutting blades

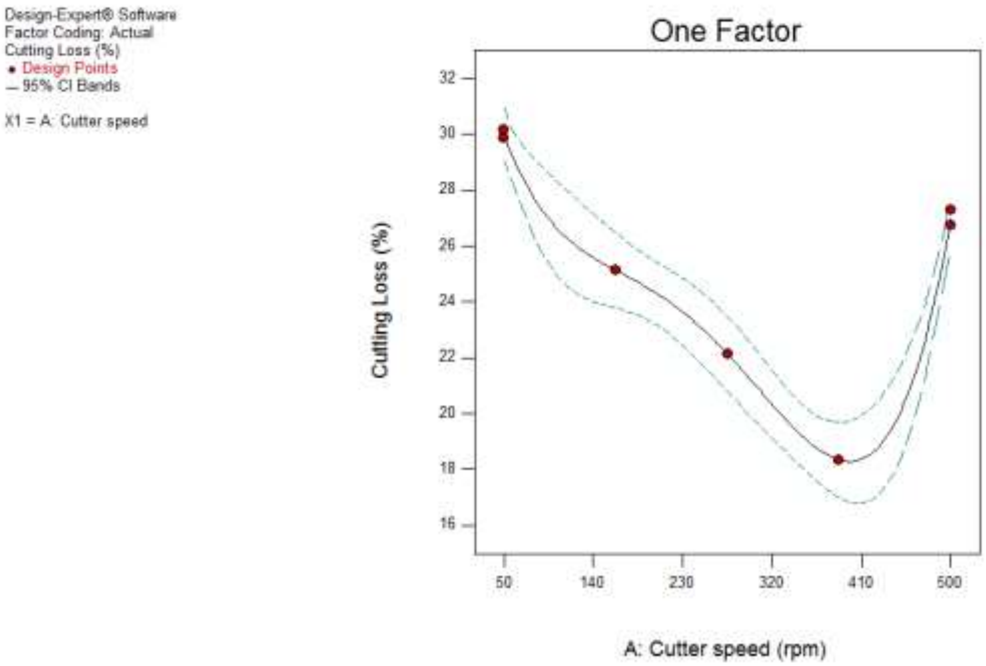

Figure 4. 14:Surface curve between cutting loss (%) of machine and cutter speed (rpm) of cutting blades

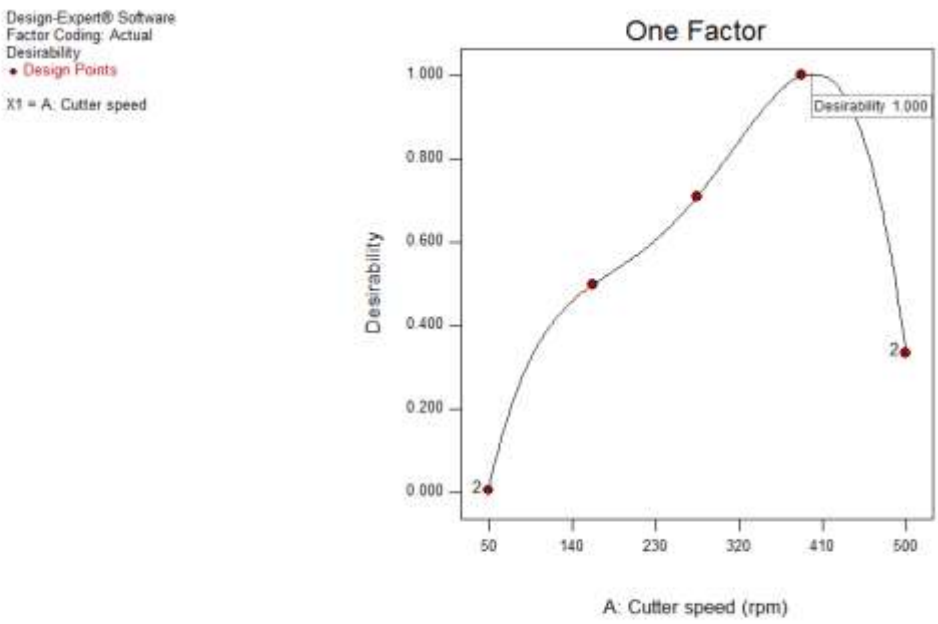

Figure 4. 15: Surface curve between desirability of machine and cutter speed (rpm) of cutting blades

Table 4.16: Optimized independent variables and predicted and experimental values of dependent variables at optimum conditions (n=3)

Variables	**Range**	**Optimum Conditions**
Cutting speed (rpm)	50 to 500	398.75
Response	**Predicted values by model**	**Experimental Values**
Cutting efficiency (%)	169.63%	170.14±4.43%
Cutting loss (%)	19.19%	18.29±3.13%

4.5 Storage study of fresh-cut tender jackfruit[4]

Preliminary studies (with support of available literature on MAP of fresh cut fruits and vegetables) were performed to minimise the number of experiments.

Table 4. 17: Testing the quality attributes of fresh cut tender jackfruit during storage in different packaging material.

Independent variables	**Dependent variables**
Packaging materials (LDPE, HDPE, PP)	Percentage Weight loss
Concentration of CO_2 (0,10%)	Browning index
Concentration of O_2 (5, 20%)	Microbial Growth

[4]This work has been published as: Rana, S.S., Pradhan, R.C., & Mishra S. (2018). Image analysis to quantify the browning in fresh cut tender jackfruit slices. *Food Chemistry*. *(SCI journal.*

4.5.1 Change in the concentration of carbon dioxide and oxygen during storage

The respiration rate as CO_2 evolution of fresh-cut Jackfruit ranged from 89.3±1.2 to 147.0±7.1 nmol/kg-s reported in literature, which is higher than Other many other fresh-cut vegetables (Barth *et. al.*, 2002). Oxygen levels inside the packages of MAP and super atmospheric O_2 treatments significantly decreased over time except those in the perforated packages (Figure 4.16 and 4.17) Both film OTR and initial O_2 level in the packages significantly affected O_2 reduction rates and thus the final O_2 levels in the packages. O_2 level decreased rapidly, reaching on day 10 to 15 for all the combinations of MAP. The O_2 level in decreased at a slightly slower rate, after day 10 and. The differences between these two treatments are primarily attributed to their film permeability, as expected. This is because the function of film barrier properties here is to prevent the O_2 from being transmitted outward rather than inward.

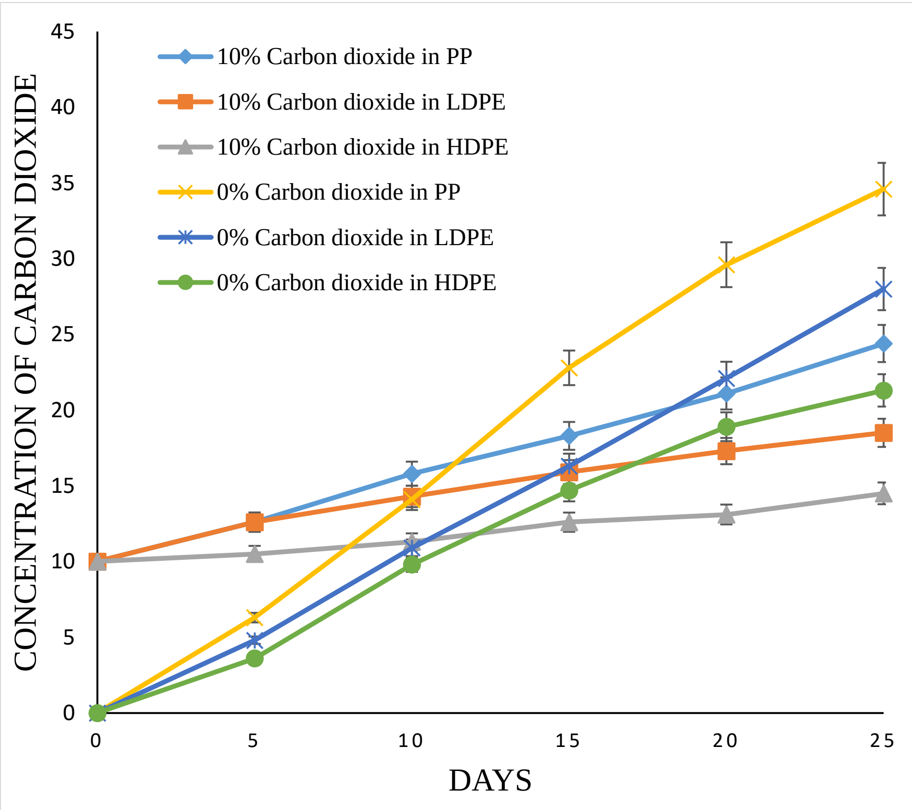

Figure 4.16: Change in the concentration of CO2 during storage when packed in different MAP conditions and packaging material

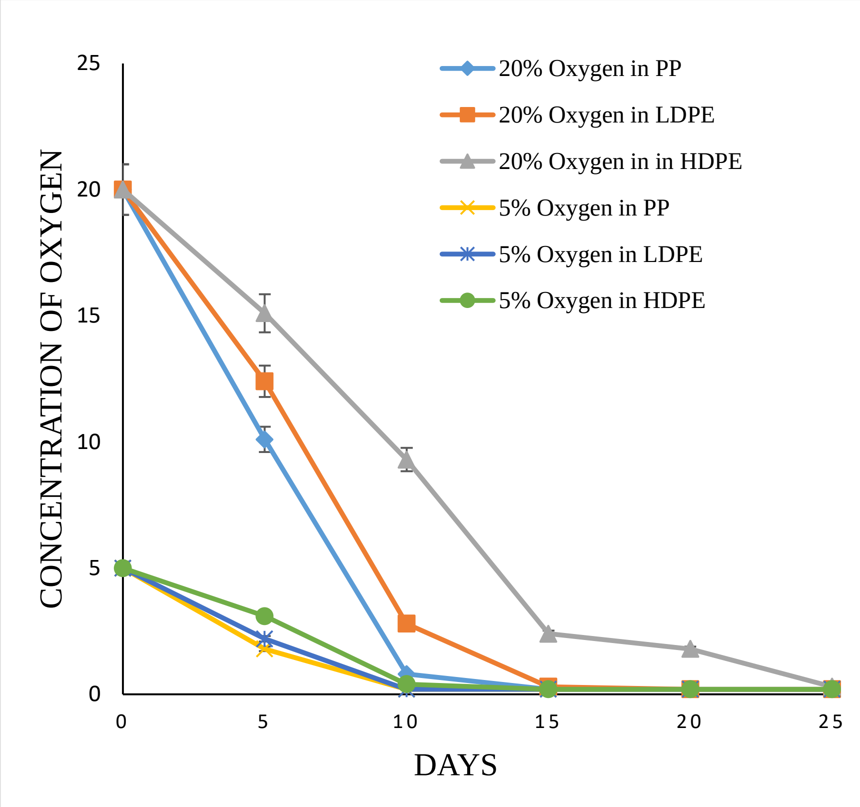

Figure 4.17: Change in the concentration of O2 during storage when packed in different MAP conditions and packaging material

4.5.2 Change in the browning index during storage in different MAP packaging

Enzymatic browning in terms of browning index (BI) as values has been presented in Figures 4.18 and 4.19, for the pretreated samples under different MA conditions during storage. After 5 days of storage, control samples recorded nearly 1.5–1.7-fold higher BI values whilst pretreated samples showed a restricted rise of 1.2–1.4-fold under different MA conditions. The difference in browning intensity was found to be significant ($P<0.05$) between the two experimental sets described and amongst the different MA conditions. After 14 days, HDPE samples were found to have restricted increase in BI as compared to other MA techniques used. Control MA samples showed a rapid rise in BI from the 10^{th} day onwards. Low O_2 atmosphere generated during the MA conditions also plays an important role in terms of anti-browning function, due to the anti-respiratory activity and lower availability of molecular oxygen required for the PPO-mediated enzymatic browning.

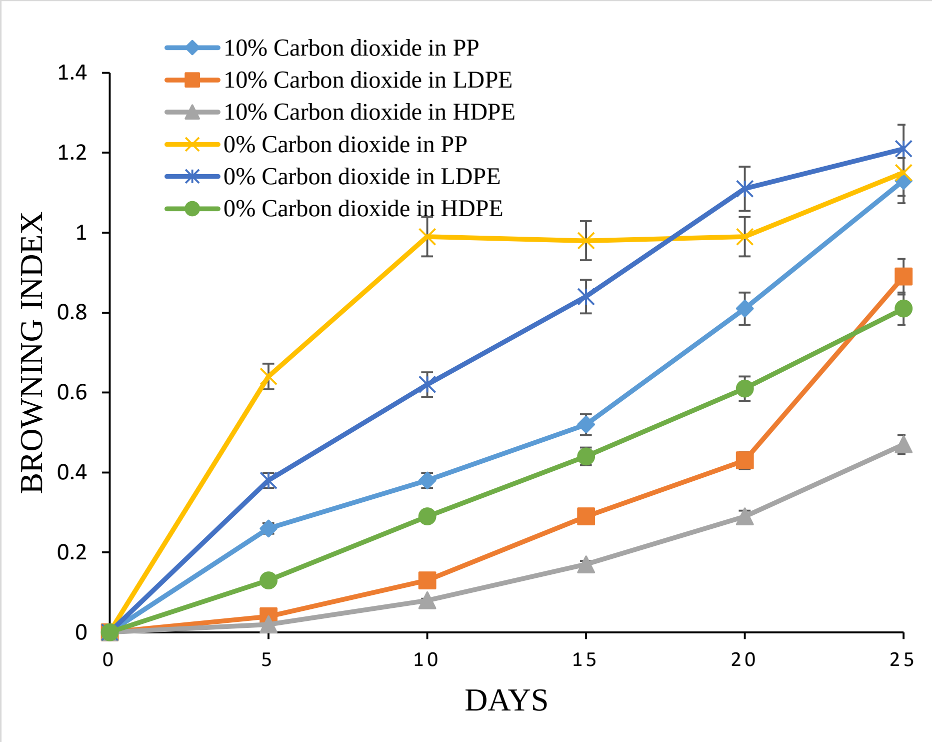

Figure 4.18: Browning Index values of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

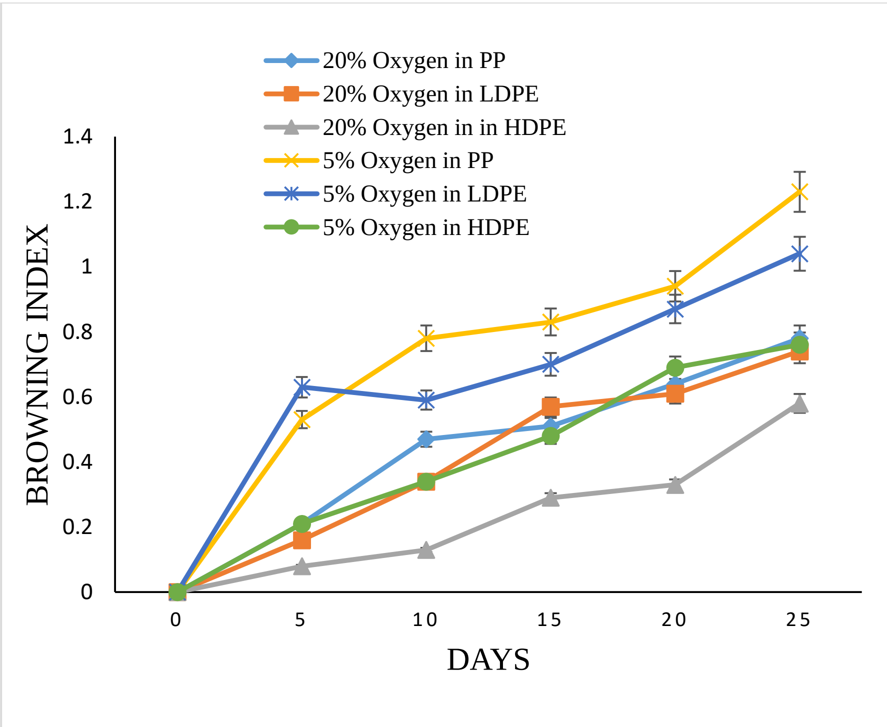

Figure 4.19: Browning Index values of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

4.5.3 Percentage weight loss and microbial load during storage in different MAP packaging

The measurement of juice leakage (tissue electrolyte leakage) has been used as an indicator for tissue and membrane integrity in various studies (Murata, 1989; Marangoni *et. al.*, 1996). We have previously observed that electrolyte leakage was closely related to the quality and shelf-life of fresh-cut jackfruit slices in different packaging materials and conditions (Kim *et al.*, 2004). In this study, (tissue electrolyte leakage) weight loss is associated with juice leakage is measured over time (Figure 20 and 4.21). There was an increase in weight loss was measured in all the during day 5 to day 10, coinciding with rapid quality deterioration (Figure 22 and 4.23). This may indicate the onset of anaerobic respiration and CO_2 injury, result from rapid accumulation of CO_2 and depletion of O_2.

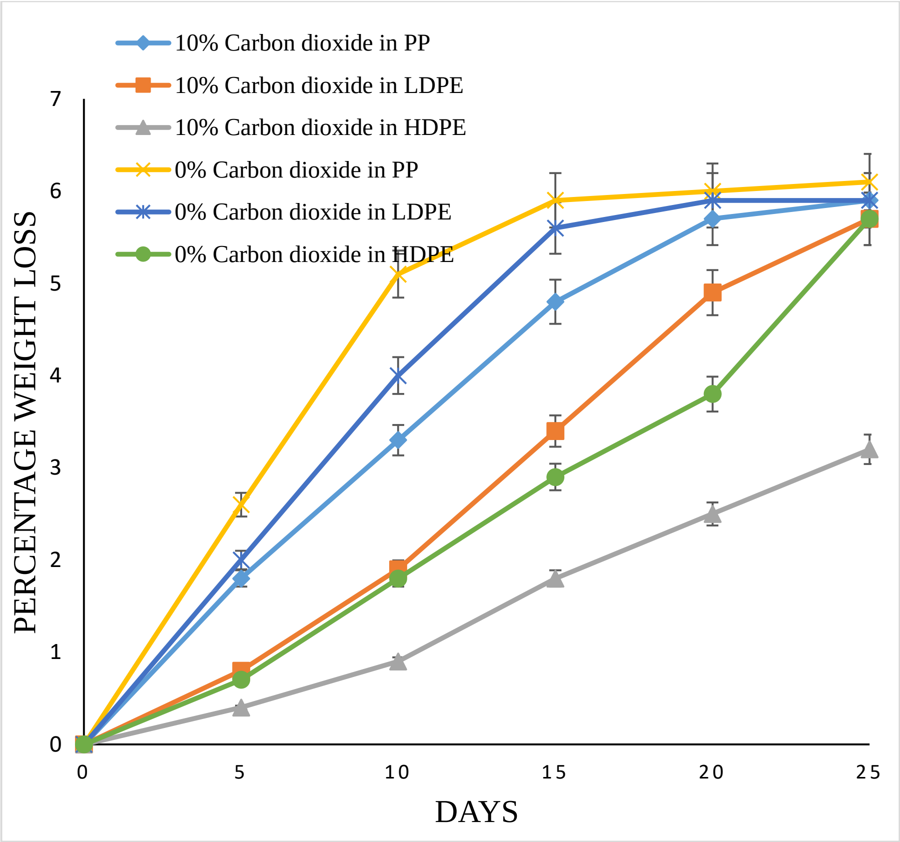

Figure 4.20: Percentage weight loss of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

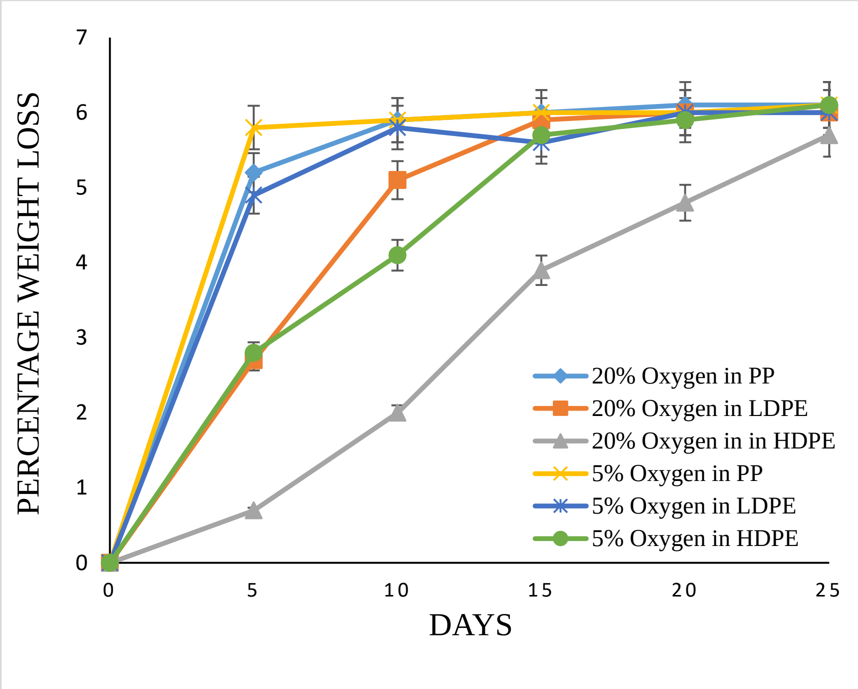

Figure 4.21: Percentage weight loss of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

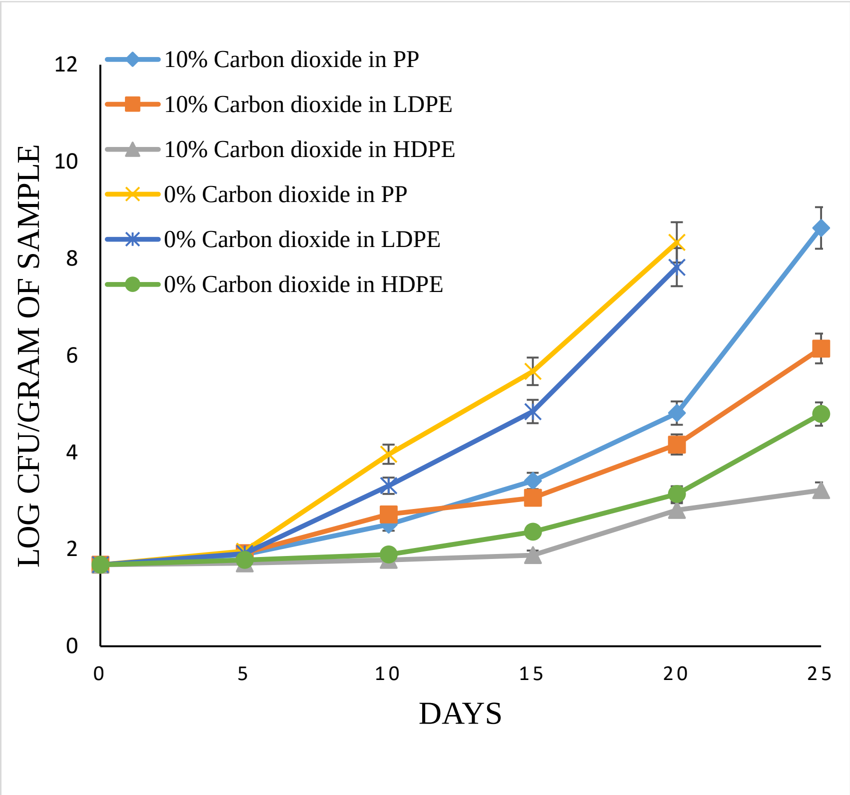

Figure 4.22: Microbial load of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

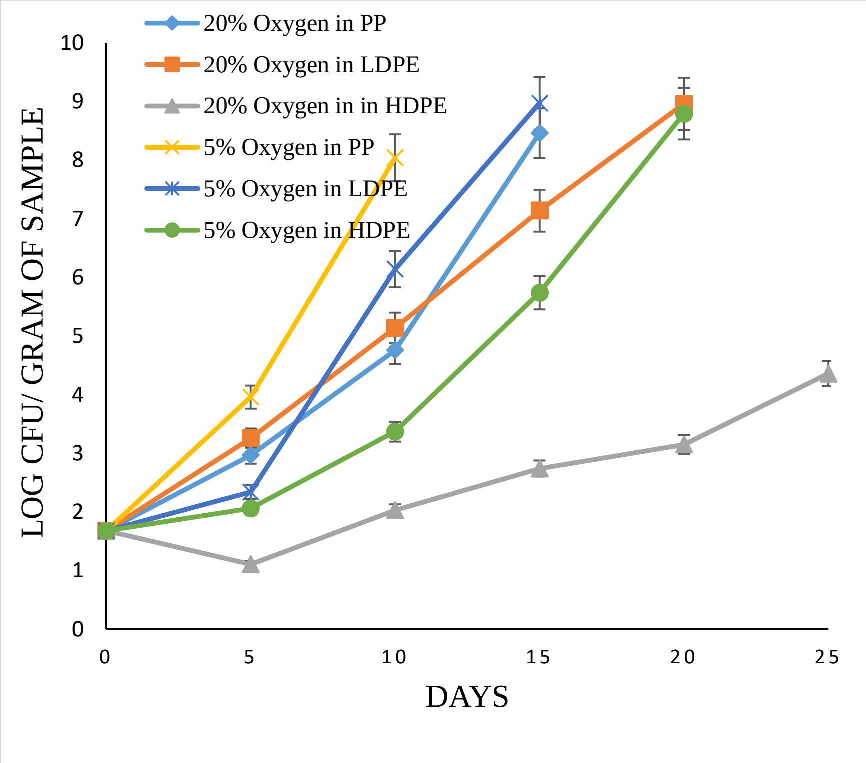

Figure 4.23: Microbial load of tender jackfruit slices during storage when packed in different MAP conditions and packaging material

4.6 Relationship between browning index and storage of tender jackfruit

Browning index (BI) was measured to estimate the browning in fresh cut tender jackfruit slices. After 3 days of storage, the control and normally packed sample's browning index was high (nearly 0.5) (at level of significance, P<0.01). Phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO) and peroxidase (POD) are enzymes that are accountable for browning of fresh cut vegetables and fruits. Enzymatic activity of these enzymes has been extended rapidly during storage of fresh cut tender jackfruit. As indicated, the change in colour during day 1 and 2 of storage was midst and this represents that enzyme activity during this time was less.Yet it suddenly increase on 3rd day in normally packed and conrtol samples and the signs of early browning were also visible. This resembled the results procured from the sensory evaluation and these results exhibited the tender jackfruit slices browning developed more quickly in the control group.

Where as in case of V-packed and MA-packed groups the browning index (BI) was low until day 6 (Figure 4.24). The value of BI for V-packed on day 6 was 0.214 which suddenly raised to 0.399 on day 8. Whereas, in case of MA-packed group the BI increased suddenly from 0.188 to 0.316 between day 4 and day 6, respectively. These results shows that packaging helps in delaying the browning process. Hence browning can be reduced to certain limits with the help of packaging. V-packed samples were having the longest shelf life i.e.10 days among different packaging material tried in this experiment.

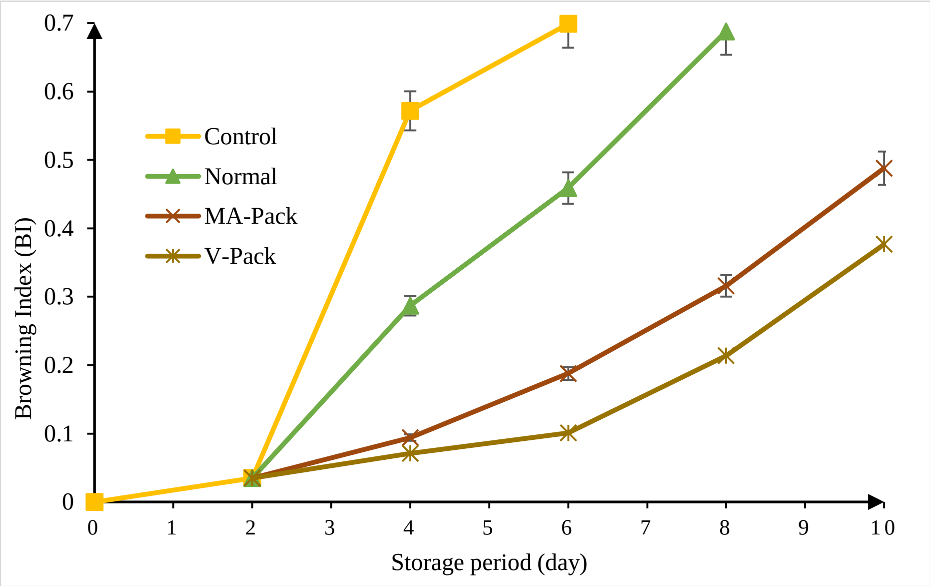

Figure 4.24: Browning Index values of tender jackfruit slices during storage when packed in different packaging conditions.

4.6.1 Changes in colour values of tender jackfruit slices using sensory evaluation

The change in colour of packed tender jackfruit slices in initial 2 days was not significant ($P<0.01$). ΔE value was significantly less in that duration (less than 3 points). Whereas after the third day the browning developed quickly during storage. The results of the sensory evaluation from Figure 4.25, clearly depicts the influence of browning on tender jackfruit slices and its colour change. Control and normally packed tender jackfruit slices showed higher scores (i.e. nearly 8) than the MA packed and vacuum packed group (i.e.<6) during storage. Specifically, after 8 days of storage, the control group demonstrated a significantly higher score than the normally packed group. Since, initial concentration of gases in normally packed samples were CO_2=0.04%; O_2 20% (same as air). In case of MA packed samples, the concentrations were CO_2 = 10%; O_2 = 10%, where as in case of V-packed there were no gas. These outcomes demonstrate that CO_2 and ethylene gas advanced the aging and browning of samples. Connections between ethylene or carbon dioxide gas and the maturing of biological product from fruits and vegetables have been accounted for in many studies (Brecht, 1995; Buron-Moles et al., 2015; Villalobos-Acuna et al., 2011). In this study, the ethylene generator influenced aging and browning of fresh cut tender jackfruit slices.

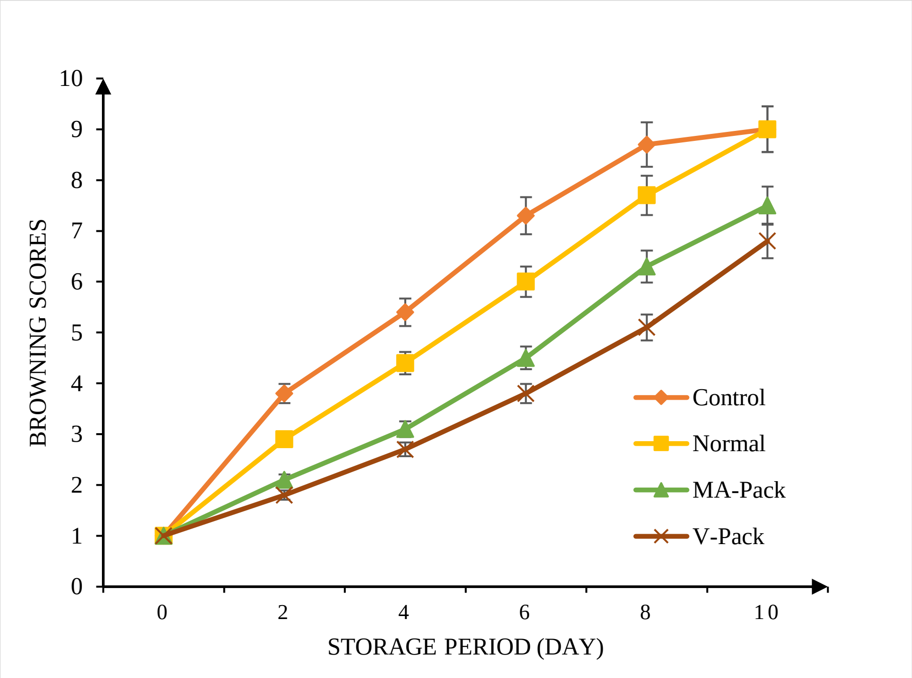

Figure 4.25: Browning scores for sensory analysis of tender jackfruit slices during storage when packed in different packaging conditions.

On the other hand, a few researchers have detailed that a high concentration of CO_2 gas influences the browning during post-harvest processing of products from fruits and vegetables (Guevara et. al., 2003; Zhang et. al., 2013). In this investigation, fresh cut tender jackfruit slices were influenced by oxidative reaction generated because of high-CO_2 injury. But, further, the examination is required to get data to understand the fundamental mechanism connection between browning and high-CO_2 injury.

4.6.2 Changes in colour value of tender jackfruit slices using colorimeter

Changes in the CIE L* a* b* values (i.e. ΔE) assessed by utilizing a colorimeterare shown in graph (Figure 4.26). In general, L* and b* values diminished anda* values increased for all the samples during storage. Specifically, the control group demonstrated a fast reduction in the L* and b* values and an increase in the a* values. This demonstrated control group develops browning more rapidly, steady and same with the results of the image analysis and sensory test.

The initial L* value and b* for fresh cut tender jackfruit slice was 74.31 and 30.16 respectively. Which represents that tender jackfruit slice was bright when it was fresh. There was significance decrease in L* values in all the groups (i.e. Control; Normal; MA-pack and V-Pack. L* value decreased to 46.22, 54.36, 61.61 and 68.74 in control, normal, MA pack and V-Pack samples respectively after 10 days of storage. Similarly, b* values decreased to 12.54, 15.11, 20.2 and 22.05 in control, normal, MA pack and V-Pack samples respectively after 10 days of storage.

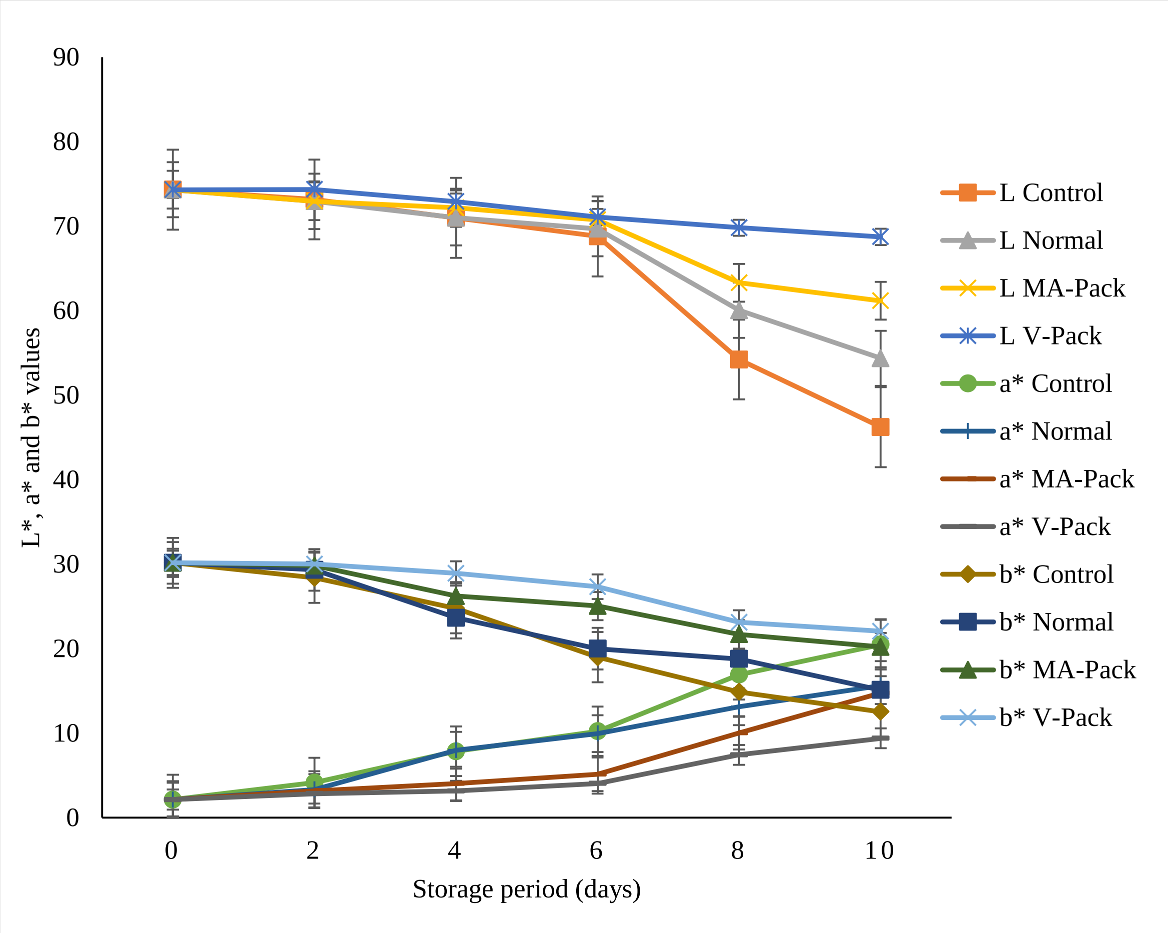

Figure 4.26: Changes in L*, a* and b* Values of tender jackfruit slices during storage when packed in different packaging conditions determined by using colorimeter.

In case of a* values there were increase in values for all groups. The initial value for fresh cut tender jackfruit slices on day 0 was recorded as 2.14. The increase in a* values explains the increase in dullness in colour of tender jackfruit slices during storage. The a* values increased to 20.48, 15.63, 14.74 and 9.39 in control, normal, MA pack and V-Pack samples respectively after 10 days of storage. On close inspection of these values one can find that the rate of loss in colour (ΔE) were different in different groups Hence the rate of loss in colour (ΔE) value was highest in control samples, least in V-packed samples and moderate in Normal and MA-packed samples.

4.6.3 Changes in colour value of tender jackfruit slices using image analysis

Changes in the RGB and CIE *L**a*b** colour values are shown in Figure. 4.27 and Figure 4.28. For the RGB colour value decreased consistently. The control and normally packed groups showed lower values. This result showed a similar tendency to that of the sensory test and enzyme assay. Browning of tender jackfruit slices develops as the storage period increases. First, the colour change (ΔE) was slow, but as the storage time increase beyond 3 days the browning develops on the tender jackfruit slices. For this reason, decrease in the G value is a more accurate indicator than the R and B values.

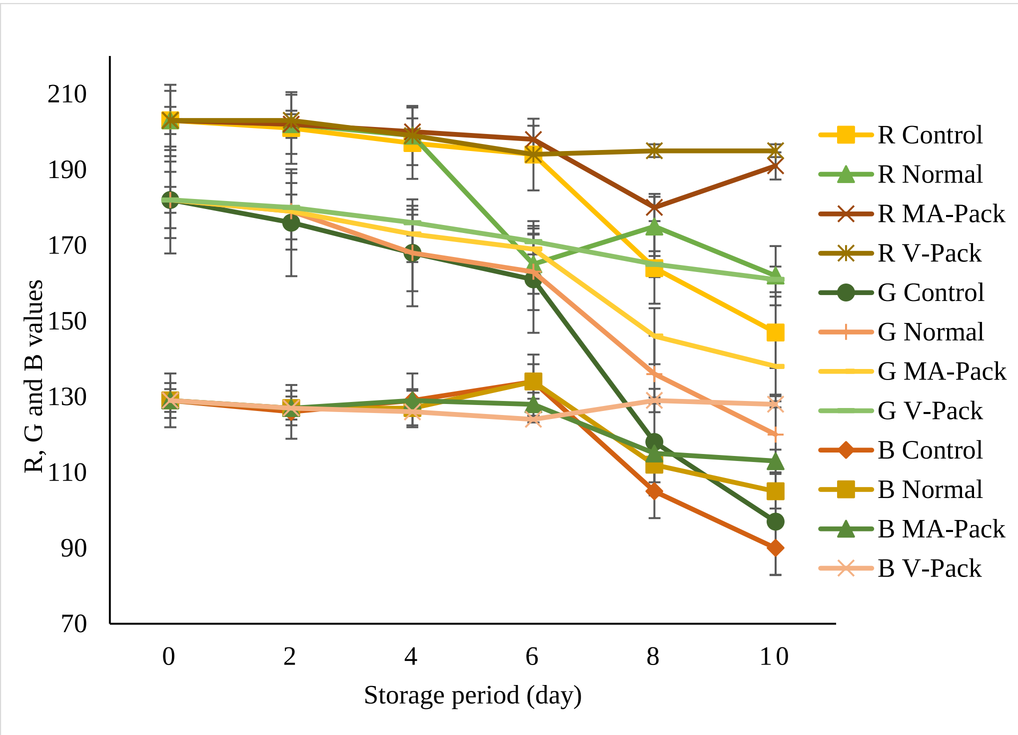

Figure 4.27: Changes in R, G and B Values of tender jackfruit slices during storage when packed in different packaging conditions determined by using image analysis.

The decrease in R, G and B values of samples were significant (level of significance, $P< 0.05$). The initial values for R, G and B were 203, 182 and 129 respectively on day 0. These values were decreased with different rates in case of control, normal, MA-pack and V-pack samples. The rate of change of colour was highest in control samples, least in V-packed samples and moderate in Normal and MA-packed samples.

The CIE $L^*a^*b^*$ values consistently increased or decreased. Accordingly, the lightness and yellowness decreased and redness increased. Many studies have reported that the L^* value decreases and the a^* values increase with the browning of fruit (*Arias et. al., 2009; Cho et. al.*, 2012; Chung *et. al.*, 2015).

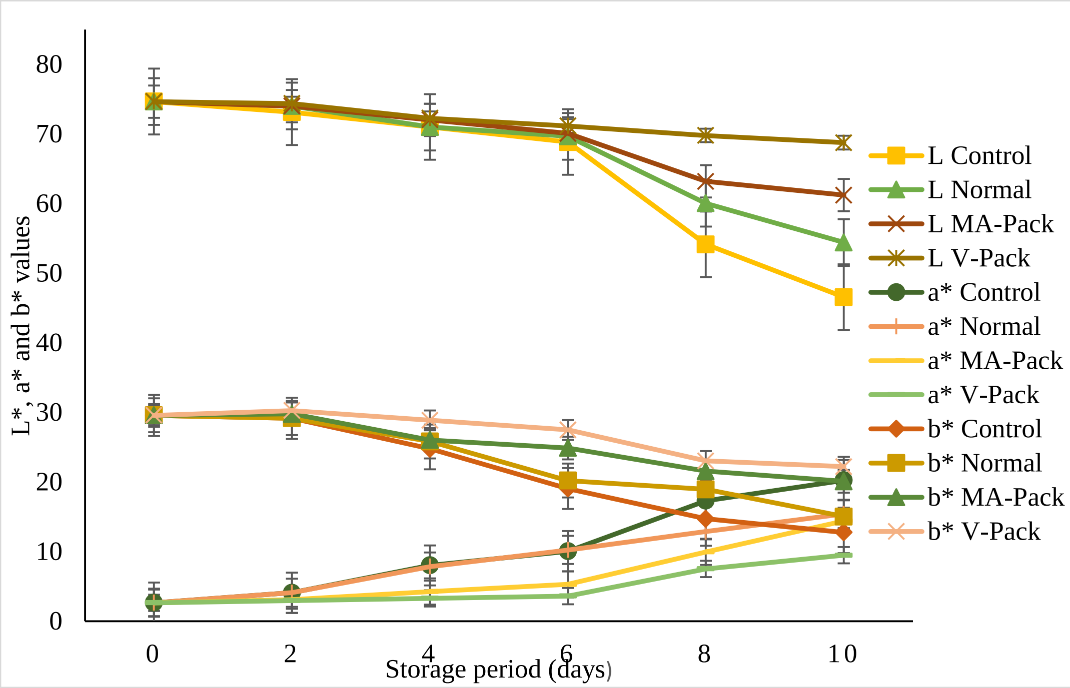

Figure 4.28: Changes in L*, a* and b* Values of tender jackfruit slices during storage when packed in different packaging conditions determined from image analysis.

The browning was homogenous. Particularly in tender jackfruit slices, colour change is simultaneous in all samples. Image analysis can be utilized to break down the complete surface of a sample in one RGB value and this values can be utilized to determine the colour change a sample. This study demonstrated that the RGB value of sample and CIE $L^*a^*b^*$ values found by using image analyses are appropriate for the investigation browning of tender jackfruit slices.

4.6.4 Correlation coefficient

The correlation coefficients between the sensory evaluation and the outcomes from other analytical methods presented in Figure 29. From the R and L* values it can be concluded that the image analysis demonstrated a high correlation coefficient, more than 0.9. For the colorimeter results, the CIE L* value demonstrated the highest correlation coefficient (0.963) and the CIE a∗ and b∗ values indicated relatively frail correlation. Image analysis depends on the overall picture of the sample and therefore able to analyze the entire surface of samples.

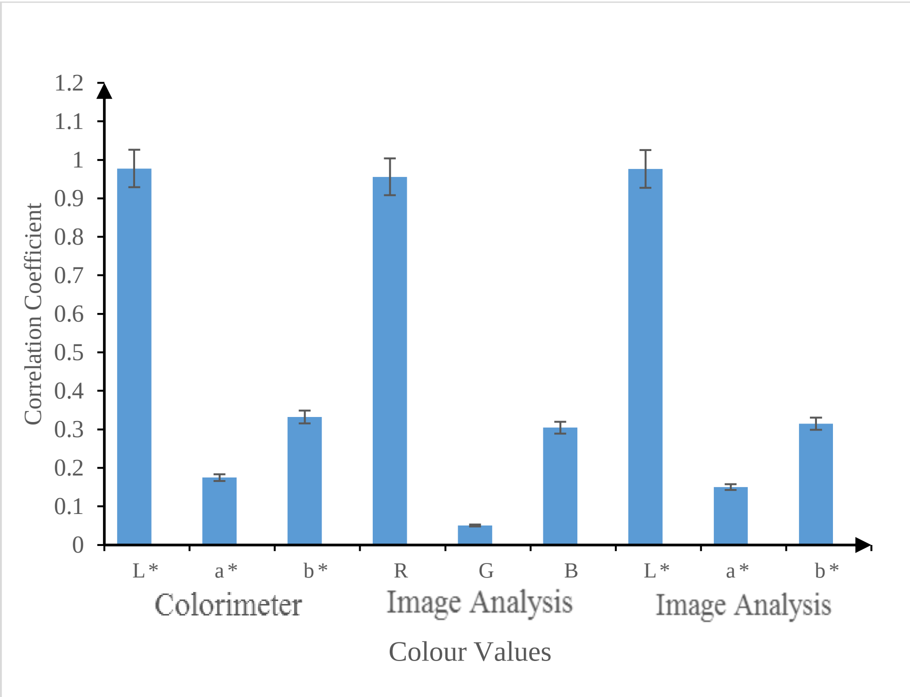

Figure 4.29: Correlation coefficients.

From Figure 4.29 it can be concluded that the difference in colour determined by colourimeter and image anlysis methods were negligible and hence the correlation coefficient was significantly high (about 0.963). The difference in values might be because colorimeters is that they are point specific not area specific but on the othewr hand image analysis method used was area specific.

4.7 Cost economic analysis of the developed machine

Technology validation and commercialisation of the designed machine needs proper cost economic analysis. The slices made and machine operational costs directly depend on the raw materials. In this analysis, it was assumed that the Jackfruit is collected at the peak harvest season (May to July), when price of the fruit is at its lowest possible rate. Tender jackfruits were procured at an average cost of ₹3INR /kg. The details of raw material cost involved in the fabrication of machine given in Table 4.17.

Table 4. 17: Raw material cost calculation.

Sl.	**Details of items**	**Quantity in Kg**	**Unit Cost ₹ INR**	**Total Cost ₹ INR**
1	Fabricated parts			
2	Raw Material (RM)			
3	Stainless steel (304)	40 kg	250	10000
4	Ferrous Material			
5	M.S.:-Angle, Flat, Sheet, Rod, Pipe, Plate, Channel, Square Box, Stainless Steel Sheet, etc.	120 kg	50	6000
6	Polymer sheets			500
			Sub Total RM	16500
			Raw Material Scrap (RMS) Cost 3%	495
			Sub Total RM+RMS	16995
7	Fabrication Cost (FC), (70-120% depending upon machine design) In this case 120% of RM	Sub Total FC		20394
8	Fabricated part cost (FPC) = RM+FC	Sub Total FPC		37389
	Standard Components/Parts, (Bought out parts)			
9	Power Transmission: Bearings, Pulley, V-Belt, PU Sheet, PU Round Belt, Hinge, etc.			4300
10	Fastening Components: Nuts, Bolts, Screws, Split Pins, Fly Nuts, Washers, etc.			500
11	Oil & Lubricants, Grease, etc			300
12	Power Unit (Electric Motor, Electric Wire, Cable, Switches, pump etc.)			15500
			Sub Total SP	20600
13	Cost of fabricated part (FPC) + Standard parts (SP)		Sub Total	57989
			Machine cost	**₹58000INR**

A total of 180 operation days (i.e. 4 summer months + 2 months of winter) per year with 8 hours of operation per day were considered. A period of ten years was considered for machine depreciation with an annual maintenance cost at a rate of 2% of the initial cost of the machine. Besides this, the insurance cost (2% of the machine cost), interest on capital

(10% per annum), labour wages per day (@ ₹300 INR) was also assumed. Fresh cut tender jackfruit slices have a market price of ₹30 INR /kg. Details of cost economic analysis is given in Table 4.18.

Table 4. 18: Cost economic analysis for the developed machine

Parameters	Values
FIXED COST	
Cost of the machine, ₹ INR	58000
Effective capacity of capacity, kg of fruit /h	25
Life of machine, year	10
Hours of operation per day	8
Days of operation per year	180
Annual processing capacity for the raw material, kg	36000
Machine depreciation (salvage value of @ 10% of initial cost), ₹ INR.	5800
Interest on cost of the machine @ 10% per annum	5800
Insurance @ 2 % of the cost of the machine ₹ INR per annum	1160
Housing @ 2% of the initial cost of the machine per year, ₹ INR	1160
Annual Fixed cost, ₹ INR	13920
VARIABLE COST	
Annual repair and maintenance cost @ 2% of machine cost, ₹ INR	1160
Annual wages of one labour @ ₹ 300 INR per labor per day	54000
Cost of Jackfruit @ ₹ 3.00 INR per kg for 36000 kg	108000
Interest on cost of procured Jackfruit @ 10% per annum, ₹ INR	10800
Annual cost of storage/losses of Jackfruit @ 5% of its cost, ₹ INR	5400
Annual cost of packaging of Jackfruit @50% of its cost, ₹ INR	54000
Annual Present value of Jackfruit, ₹ INR.	178200
Annual operating/variable cost, ₹ INR.	233360
REVENUE	
Average content of jackfruit slice from fruit, %	48
Annual production of jackfruit slices from machine, kg	17280
Annual production of waste material from machine, kg	18720
Revenue from the sale of jackfruit slices @₹ (INR) 30.00/kg ₹ INR.	518400
Total annual revenue for fruit processing, ₹ INR.	518400
Benefit-Cost-Ratio	2.10
Return-On-Investment, %	209.61
Pay-Back-Period, Year	0.1
Break-even point (kg sales)	844
Cost of processing 1 kg of *Jackfruit* ₹ INR.	3.46

Chapter 5

Summary and conclusions

India is the second largest producer of the fruit in the world and is considered as the motherland of jackfruit. For centuries jackfruit plays a vital role in Indian agriculture and culture. But, a very low percentage of total production is consumed as food (30-35%) and 70% is lost during pre- and post-harvest stages. There is difficulty in the harvesting of fruits, separation of bulb from the rind, very less harvesting and post-harvest processing techniques and machineries are available for jackfruit. Various equipment for tender jackfruit like jackfruit peeling, jackfruit cutting and packaging are not at all available. This problem limits the potential use of the fruit. Uncertainty and variability in the yield and quality are the major problems involved in the utilization of jackfruit. Hence, there is a need to develop the minimal processing technology that can process the fruit at commercial level. This work aimed at coming out with a need-based and low-cost solution for processing of fresh cut tender jackfruit to ensure food and nutritional security. A stable marketing chain is not in existence for jackfruit. Transactions at the farm level occur mainly on ready cash payment basis and rarely on credit. Middlemen decide the market prices resulting in the exploitation of the producers. Since jackfruit is very bulky and semi-perishable, processing can reduce transport costs, prevent spoilage, increase shelf life. Processed products usually command higher prices then unprocessed products. Taking in this view the appropriate methods for post-harvest handling, processing and product development for local and regional markets should be developed. At the local level, technology needs to be transferred to promote products, packaging techniques and better long distance transportation. To achieve this, a complete package of work was taken up starting from finding various properties of the fruits, utilizing those properties for design and fabrication of a tender jackfruit peeling and cutting machine, solving the browning problem during the processing of tender jackfruit, and packaging of fresh cut tender jackfruit in modified atmospheric storage to achieve better shelf life. Objective wise conclusions and recommendations for future work are summarized below.

5.1 Physico-chemical and textural properties of tender jackfruit

As the maturity of tender jackfruits shifted from stage 1 to stage 4, the physical properties like weight, length, and diameter of soft and hard varieties were changed. The soft variety of jackfruit found to be smaller in weight, length, and diameter than that of hard variety. Jackfruit from both the varieties tends towards oblong shape and moisture content decreases as the maturity increases from stage 1 to 4. While other parameters like pH, total solids and ash content are independent with respect to maturity stages. TSS and TDS increased by 240%, 90.98%, 162.96% and 145.63% for both hard and soft variety, respectively, at stage 1 to 4. The soft variety of jackfruit at any stage has shown higher nutritional properties than that of hard variety. The mechanical and textural properties of the tender jackfruits of both varieties are depends on the stage of maturity. All these basic properties will be helpful to various researchers, scientists, food processing industries, etc. for the postharvest processing of the tender jackfruit.

5.2 Solving the problem of fresh-cut tender jackfruit

The methodology used to optimize the pre-treatment for minimal processing of fresh cut tender jackfruit was response surface methodology (RSM). Study was conducted with the aim of extension in shelf life of fresh cut tender jackfruit and the results found were very promising and positive. There was increase in shelf life of fresh cut tender jackfruit by 10 to 15 days in refrigerated conditions. With increase in shelf life the quality of tender jackfruit was also retained in terms of colour and firmness. There was no or minimum browning recorded in samples and the overall acceptance of fresh cut tender jackfruit was higher in terms of overall acceptability. The treatment adopted for minimal processing was dipping of fresh cut tender jackfruit slices in solution of different concentration of $CaCl_2$ and citric acid for various time interval. The response variables were browning index, overall acceptability, change in colour and firmness. The model used to determine the optimized conditions for pre-treatment as minimal processing was second order polynomial model. From the experimental data it was found that the model was having good fit with high R^2 (0.942) value. From the model and with the help of RSM the optimized conditions were 3.17% concentration of $CaCl_2$ and 1.37% concentration of citric acid for 6.78min treatment time. The optimized conditions for processing ensure maximum retention of quality and longer shelf life.

5.3 Design, development and fabrication of peeling and cutting machine for tender jackfruit

The machine was designed by using SolidWorks-2015 and fabricated for tender jackfruit. It can process all sizes of tender jackfruit with the effective throughput capacity of 25 kg/hr. All food contact parts of the machine are of Stainless Steel- Grade 304. The machine is being capable of washing, peeling and cutting of tender jackfruit effectively. Machine is properly protected from all sides to prevent any chances of accidents or hazards to operator and can be operate at 3 phase (AC) supply at 220V and 50 Hz. The capacity of chemical holding tank is 30 liters and a pump was used to create the turbulence in tank. The peeling assembly consists of adjustable platforms to hold any size of jackfruit firmly (Length: 8 to 30cm and diameter). The hollow shaft to spin the jackfruit on its longitudinal axis is driven by motor (3 phase), with provision to control its speed. Cutting assembly contain roller blades with serrations on the sharp edges which cut the jackfruit in slices of 4.5cm.

5.3.1 Evaluation and optimization of the machine performance

The operating conditions such as forward speed of peeling arm, rotating speed of jackfruit and rotating speed of cutter were optimized for maximum efficiency of machine and minimum loss. The desirability function analysis suggested optimum values of forward speed of peeling arm, rotating speed of jackfruit and rotating speed of cutter as 160.22rpm, 90rpm and 398.75rpm, respectively with a desirability value of more than 0.87. The optimized performance indices of the machine such as peeling efficiency, peeling loss, peeling time, cutting efficiency and cutting loss were 75.86±3.58%, 13.97±2.87%, 5.5±0.5 min, 170.14±4.43% and 18.29±3.13%, respectively. Response surface models for operation were developed with the highest repeatability. The suggested operating parameters such as forward speed of peeling arm, rotating speed of jackfruit and rotating speed of cutter were 160rpm, 90rpm and 400rpm, respectively. The operation and maintenance of the designed machine was simple.

5.4 Storage study on fresh-cut tender jackfruit slices

5.4.1 Testing the quality attributes of tender jackfruit during storage in different conditions and packaging material

The quality of fresh cut tender jackfruit slices was passively changes throughout the storage due to different kind of biochemical reactions. The synergistic effect of pre-treatment (i.e. blanching of peeled tender jackfruit slices in optimized conditions) with different storage conditions (i.e. room, refrigerated and freeze) with different packaging films (i.e. HDPE, LDPE and PP) were determined. The effect of packaging resulted in reduced loss in percentage weight loss, color and texture of jackfruit slices. The packaging of jackfruit slices reportedly increase the shelf life of fresh-cut tender jackfruit slices. Among all the treatments the HDPE was more effective than other materials for storage. The storage temperature also has vital role in increasing the shelf life of product. The storage of packed jackfruit in HDPE packs in freezed conditions was having the highest shelf life of 25 days and show highest retention of quality aspects compared to other storage conditions

5.4.2 Optimization of storage condition for storing the fresh-cut tender jackfruit in modified atmospheric packaging

In the present study modified atmospheric (MA) packages, having package size of 13.5×13.5cm^2 for weight of 200±50g were developed for the experimental purpose. The storage study of MA packages was performed at -18±1°C and 5±1°C temperatures with considering high-density polyethylene (HDPE) packaging film. Optimization was done by using the independent parameters such as the concentration of CO_2 (0-10%) and the concentration of O_2 (0-20%). The depended variables were Browning index (BI), Total Plate Count (TPC), percentage weight loss and Overall all acceptability (OAA). The performance of film packages was evaluated for their ability to establish equilibrium condition at target levels and to extend the shelf life of the packaged fruit and vegetable. It was observed that ratio of the respiration rate of O_2 and CO_2 prominently depends upon the variation of temperature. Likewise, respiration rates of O_2 and CO_2 are also significantly depending upon the concentration of gases inside the package. The processing activities like washing, sorting, peeling and cutting enhance oxidative stress in fresh cut jackfruit during storage. It also has the ill effects on quality of fresh-cut tender jackfruit by an increase in microbial contaminations, excessive tissue softening, and depletion of phytochemicals and browning during the storage. From the response variables, the best combination of independent variables resulted in 10% concentration of CO_2 and 20% concentration of $O_2$for HDPE packaging film. At these conditions, the sample can be preserved for 15 days at 5±1°C and for 25 days at -18±1°C.

5.5 Cost economic analysis of the developed equipment

Technology validation and commercialization of the designed machine needs proper cost economic analysis. The minimal processing cost is majorly depending on the raw materials cost. By using the standard procedure various important economical parameters viz. Benefit-Cost Ratio (BCR), Pay-Back-Period (PBP), Return-On-Investment (ROI), and Break Even Point (BEP) were calculated. Fixed cost, variable cost, the values of revenue generated, packaging cost and the annually earned profit for the developed tender jackfruit machine were considered. Throughput capacity of the machine is 35 kg/hr and effective throughput capacity of the machine is 25 kg/hr. Benefit-cost ratio was 2.91. The value for Return on investment (ROI) for the machine is 209.61%. Pay-back period of the investment is very less, i.e. 34 working days. The reason behind is the after selling value of jackfruit is increased by 1000%. One has to sell at least 844 kg (break-even point) of Jackfruit slices at the rate of ₹30 INR per kg in order to recover the annual fixed cost and variable operating cost of the machine. Cost of processing minimal processing and packaging of tender jackfruit slices is ₹3.46INR per kg. The cost of the designed machine is ₹56000 INR per unit. This machine can thus very well be considered with lower operating cost with very less breakeven point and very high return on investment.

5.6 Scope of future research

The present work dealt with providing a solution for minimal processing of the tender jackfruit. Following works are suggested herewith for future.

- Utilization of by-products viz. peel and latex, from minimal processing of fresh cut tender jackfruit.
- Automation and upscaling of the designed jackfruit peeling and cutting machine.
- Facilitate the peeling cum cutting machine of tender jackfruit with optimized packaging conditions.

- Real time testing of the machine in industries and jackfruit farm.
- Demonstration and training on the machine.
- Value-addition of fresh cut tender jackfruit slices.

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Appendix A

ANOVA table for Response Surface Quadratic Model of Peeling efficiency

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	106.12	5	21.22	28.87	0.0002	significant
A-Rotating speed	3.31	1	3.31	4.50	0.0716	
B-forwarding speed	2.18	1	2.18	2.97	0.1285	
AB	6.86	1	6.86	9.34	0.0184	
A^2	90.68	1	90.68	123.36	< 0.0001	
B^2	8.89	1	8.89	12.09	0.0103	
Residual	5.15	7	0.74			
Lack of fit	4.18	3	1.39	5.75	0.0621	not significant
Std.Dev	0.86	R-Squared	0.9538			
Mean	33.02	Adj R- Squared	0.9207			
C.V	2.60	Pred R-Squared	0.9194			

df, degree of freedom; C.V, coefficient of variables; P<0.05 significant at 5% level.

Appendix B

ANOVA table for Response Surface Quadratic Model of Peeling loss

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	501.50	5	100.30	28.870	0.0002	significant
A-rotating speed	15.63	1	15.63	4.50	0.0716	
B-forward speed	10.32	1	10.32	2.97	0.1285	
AB	32.44	1	32.44	9.34	0.0184	
A^2	428.56	1	428.56	123.36	<0.0001	
B^2	42.02	1	42.02	12.09	0.0103	
Residual	24.32	7	3.47			
Lack of fit	19.74	3	6.58	5.75	0.0621	Not significant
Std.Dev	1.86	R-Squared	0.9538			
Mean	71.78	Adj R- Squared	0.9207			
C.V	2.60	Pred R-Squared	0.9194			

df, degree of freedom; C.V, coefficient of variables; P<0.05 significant at 5% level.

Appendix C

ANOVA table for Response Surface Quadratic Model of Peeling time

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	890.60	5	178.12	93.02	0.0002	significant
A-Rotating speed	10.39	1	10.39	5.42	0.0716	
B-Forwarding speed	10.47	1	10.47	5.47	0.1285	
AB	41.22	1	41.22	21.52	0.0184	
A^2	489.33	1	489.33	255.54	<0.0001	
B^2	447.11	1	447.11	233.49	0.0103	
Residual	13.40	7	1.91			
Lack of fit	2.39	3	0.80	0.29	0.8315	Not significant
Std.Dev	1.38	R-Squared	0.9852			
Mean	29.318	Adj R- Squared	0.9746			
C.V	4.72	Pred R-Squared	0.9621			

df, degree of freedom; C.V, coefficient of variables; $P<0.05$ significant at 5% level

Appendix D

Figure 1: Jackfruit cutting and peeling machine

Figure 2: Cutting assembly for cutting of machine

Fig 3: Jackfruit peeling blade and holding assembly.

Figure 4: Driver end of holding assembly

Fig 5: Driven end of holding assembly

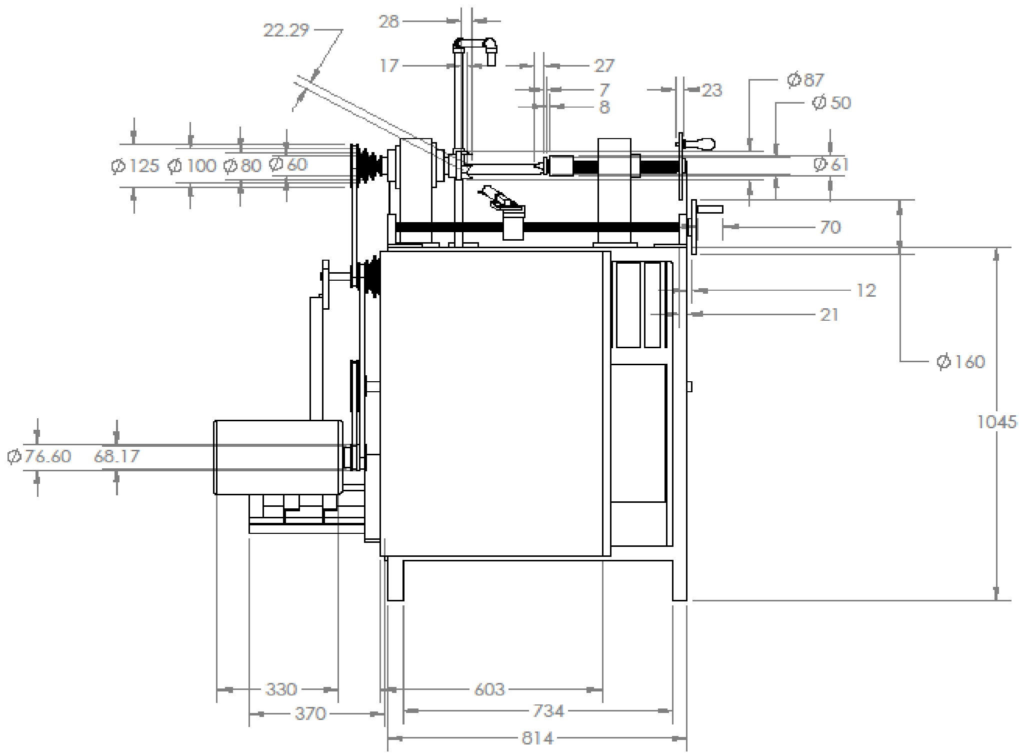

Figure 6: Front view of machine (all the dimensions are in cm)

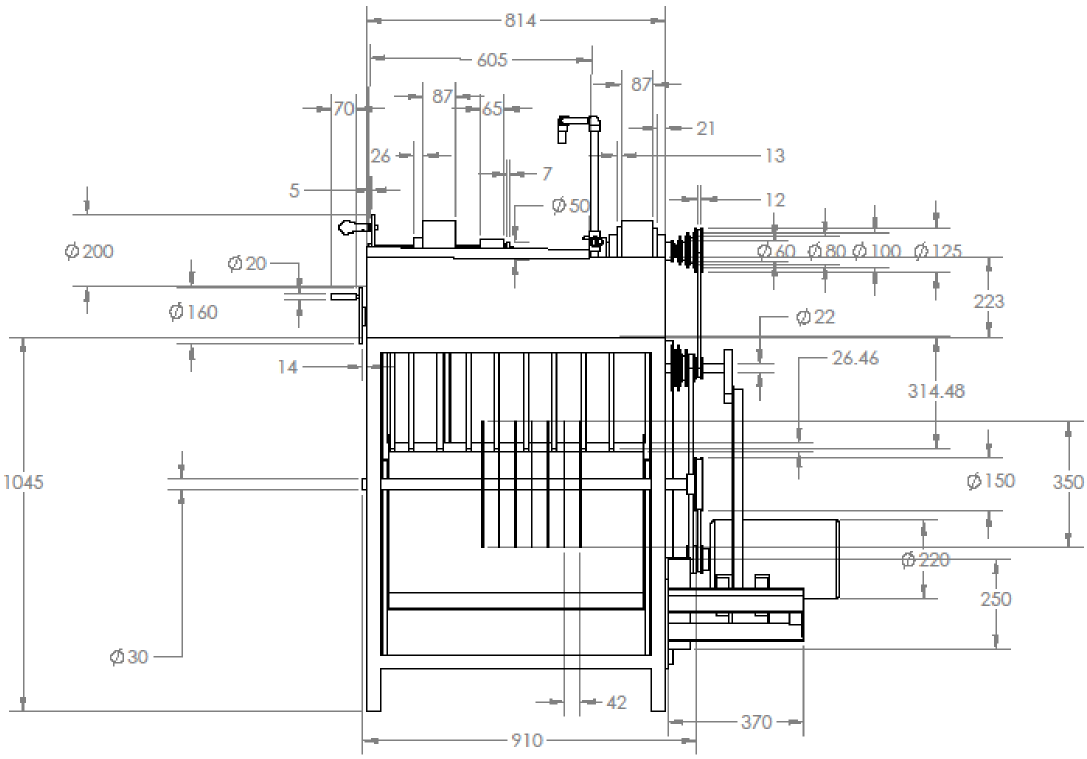

Figure 7: Back view of machine (all the dimensions are in cm)

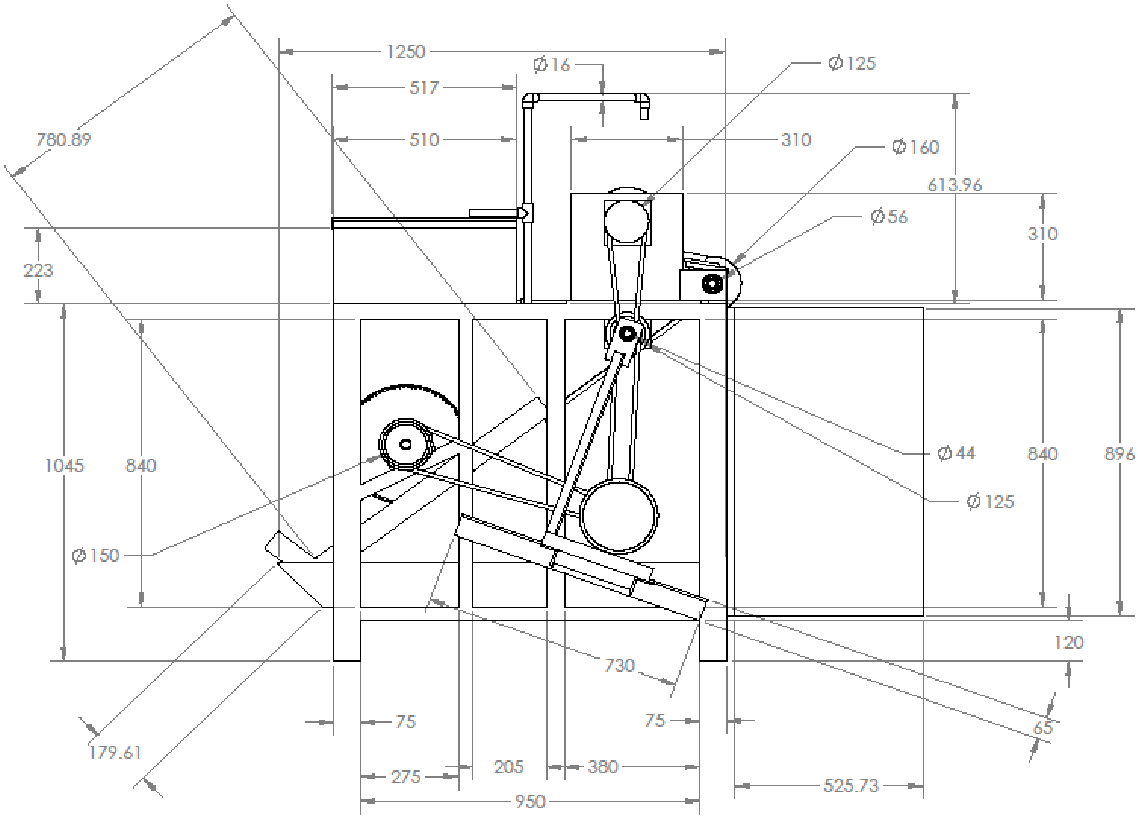

Figure 8: Left view of machine (all the dimensions are in cm)

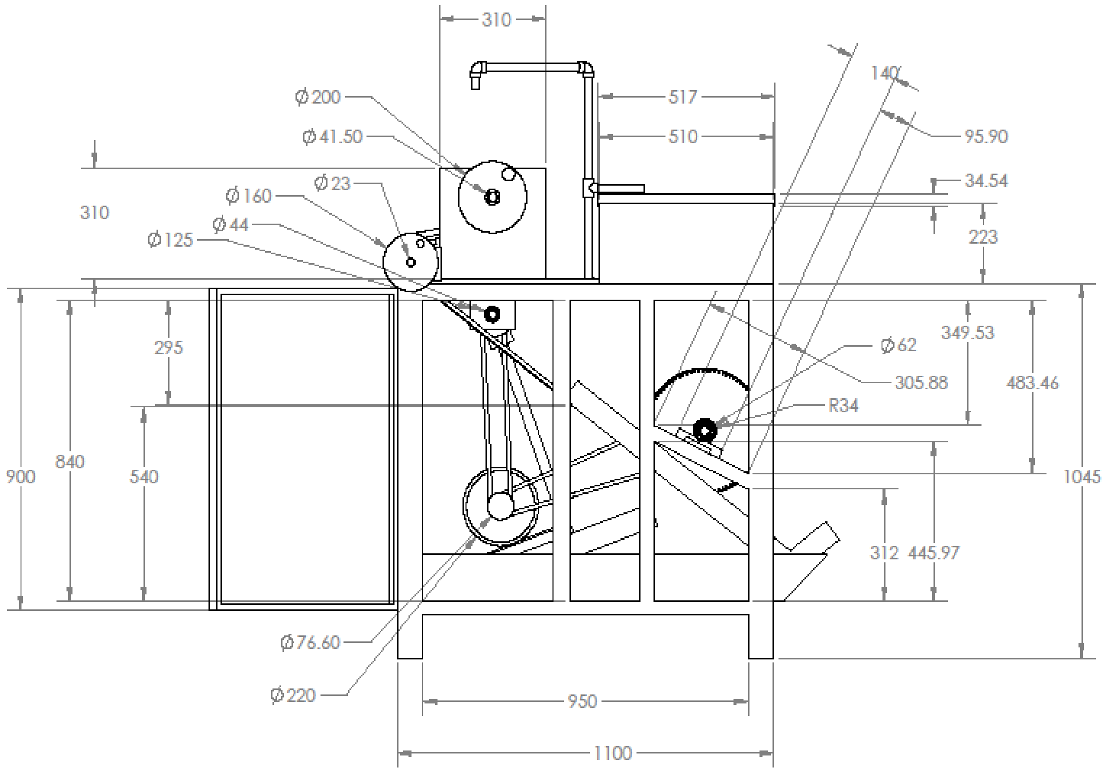

Figure 9: Right view of machine (all the dimensions are in cm)

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Education

Course	College	University	Marks %	Year
Ph.D. **Food Process Engg.**	National Institute of Technology Rourkela, Orissa	NIT Rourkela	**84.5**	Perceiving
M.Tech **Food Process Engg.**	Indian Institute of Crop Process Technology (MOFPI), Thanjavur	TNAU, Coimbatore, Tamil Nadu	**84.9**	2014
B.Tech **Agri. Engg**	College of Agricultural Engineering, Raichur	UAS, Raichur, Karnataka	**80.1**	2012
XII	Kendriya Vidhyala,Delhi-92	CBSE	**76.8**	2008
X	Kendriya Vidhyala,Delhi-92	CBSE	**82.4**	2006

Projects

1. Development of fortified fish sausage using low value underutilized fresh water fish *(Tilapia*)
2. Design and development of on-farm onion foliage and root cutting machine (MOFPI Funded).
3. Design and development of an on-farm curing device for onion, (MOFPI Funded).
4. Design and development of peeling and cutting machine for tender jackfruit.

Applied patents (Institutional Patent):

1. Equipment for peeling and cutting of tender jackfruit

List of publication

No.	Title	Journal/ Conference	Type and date
1.	Optimization of chemical treatment on fresh cut tender jackfruit slices for prevention of browning by using response surface methodology.	International Food Research Journal.	Full Length Paper, 2017
2.	Variation in properties of tender jackfruit during different stages of maturity.	Journal of food science and technology.	Full Length Paper, 2017
3.	Quality evaluation of food by thermal imaging.	International Journal of Processing and Post-Harvest Technology	Full Length Paper, Sep 2016
4.	Innovative and economically innovative and economically effective methods for processing of tender jackfruit to minimizing the wastage.	International conference on climate change and its implications on crop production and food security (ICCCICPFS)	Best Poster Award, Nov, 2016
5.	Economical and eco-friendly drying methods and modelling for retention of	International conference on climate change and its implications on crop	Full Length Paper, Oct 2016

	quality attributes of amla.	production and food security (ICCCICPFS)	
6.	Membrane filtration of fruit juice and emerging technology	International journal of food and nutritional sciences	Full Length Paper, Sep 2015
7.	*Shorea Robusta (Dipterocarpaceae)* Seed and its oil as food	International journal of food and nutritional sciences	Full Length Paper, Sep 2015
8.	A review on onion curing	International journal of biological engineering	Full Length Paper, Dec 2014
9.	A study on curing of big bellary onion when cured in modular ventilated structure and other popular techniques	IJLTET- Volume 4 Issue 4, November 2014	Full Length Paper Nov., 2014
10.	Improving milk and milk products functionality through controlled release of herbal nutraceuticals.	Proceedings of National conference on innovative techniques in development of functional foods and nutraceuticals (NCFFN-14)	Full Length paper, Feb 2014

Awards & achievements

Studies

- **National Talent Scholarship (NTS)** awarded for 4 years through ICAR. (2008-2012)
- Remarked as **University third topper** in Agricultural Engineering branch.

Sports

- Represented **college cricket team** as a captain for a year. Won many prices in cricket in Inter & Intra college cricket competition and open cricket competition as well.
- Won 4 times university level **football** competition.
- Got 2 gold medals in college level **Table tennis** competition.
- Participated and got many prices in athletics events in inter and intra college competitions.

Specialisation

Agricultural Equipment design, food plant layout and design, fruit and vegetable processing and packaging, food process engineering, unit operations in food processing.

Personal Details

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