MODIFICATION AND EVALUATION OF JACKFRUIT SEED PEELER

by

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KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

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DECLARATION

We hereby declare that this project report entitled **“MODIFICATION AND EVALUATION OF JACKFRUIT SEED PEELER”** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship or other similar title of any other University or society.

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CERTIFICATE

Certified that this project report entitled **“MODIFICATION AND EVALUATION OF JACKFRUIT SEED PEELER”** is a record of project work done jointly under our guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or society.

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ACKNOWLEDGEMENT

Any accomplishment requires the efforts of many people and this work is no different. We find great pleasure in expressing our deep sense of gratitude towards all those who have made it possible for us to complete this project with success.

First of all, we would like to express our true and sincere gratitude to our project guide, **Dr. RajeshG. K**, Asst. Professor, Department of Processing and Food Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur for his dynamic and valuable guidance, care, patience and keen interest in our project work. This project has been a result of combined efforts of our guide and us. He has been a strong and reassuring support to us throughout this project. We consider it our greatest fortune to have him as the guide for the project work and our obligation to him lasts forever.

With deep sense of gratitude and due respect, we express our heartfelt thanks to **Dr. Jayan. P.R**, Dean, KCAET, Tavanur for his professional guidance and constructive suggestions offered during this study.

We engrave our deep sense of gratitude to **Dr. Prince M.V**, HOD, Dept. of Processing and Food Engineering and **Er. Anjaly M.G**, Asst. Professor (C), Dept. of Processing and Food Engineering, KCAET, Tavanur.

We express our profound sense of gratitude to **Mr. Lenin** and **Mr.Vipin**, technicians of Dept. of Processing and Food Engineering, KCAET, Tavanur.

We exploit this opportunity to thank all the **staff members of Library**, KCAET for their ever-willing help and cooperation. We express our sincere thanks and gratitude to **Kerala Agricultural University** for providing this opportunity to do the project work.

We are greatly indebted to our **parents** for their love, blessings and support which gave strength to complete the study. We also acknowledge our friends for their support and care throughout the project duration.

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SYMBOLS AND ABBREVIATIONS

Symbols	Abbreviations
MT	Metric tonne
%	Per cent
et al.	And others
kg	Kilogram
m	Meter
s	Second
viz.	Namely
g	Gram
mg	Milligram
mm	Millimeter
cm	Centimeter
/	Per
min	Minute
rpm	Revolutions per minute
Fig.	Figure
kg/h	Kilogram per hour
etc.	Etcetera
h	Hour
SS	Stainless steel
MS	Mild steel
hp	Horsepower
Rs.	Rupees
µ	Mu
=	Equal to
η	Eta
ie.	That is

kWh	Kilowatt hour
Sl. No.	Serial number
+	Add
×	Multiply
3D	3 Dimensional
VFD	Variable Frequency Drive

DEDICATED TO ALL ENTREPRENUERS

INTRODUCTION

CHAPTER 1
INTRODUCTION

India, endowed with varied agro-climate, is highly conducive for growing numerous horticultural crops. As per National Horticulture Database (Second Advance Estimates) published by National Horticulture Board, during 2020-21, India produced 102.48 million MT of fruits and 200.45 million MT of vegetables. The area under cultivation of fruits was 9.6 million hectares while vegetables were cultivated at 10.86 million hectares. Due to lack of cold chain facility, unavailability of temperature-controlled vehicle, improper packaging and lack of proper processing techniques, nearly 25-30% of produce is wasted every year and is not efficiently utilized (Rais & Sheoran, 2015). To avoid these problems, we need technological development and diversification of these valuable fruits and vegetables which is most important in filling the ever-increasing demand-supply gap.

Jackfruit (*Artocarpus Heterophyllus*) belonging to the family Moraceae, is a tropical fruit that is widely grown in many countries like India, Bangladesh, Sri Lanka, Thailand, Indonesia, Philippines and Malaysia and in South and Central America. Currently, jackfruit production is on the rise globally due to increasing demand for plant-based meat alternatives and the fruit's versatility as an ingredient. According to the Food and Agriculture Organization (FAO), global jackfruit production was estimated to be around 6 million metric tons in 2019, with India being the largest producer, followed by Bangladesh and Thailand. In India, it is mainly cultivated in states like Assam, Tripura, Bihar, Uttar Pradesh, Kerala, Tamil Nadu, Karnataka and in the foothills of the Himalayas. In South India, the annual production of jackfruit ranks next to the mango and banana. The total cultivated area and production of jackfruit in India during 2021-2022 was 18.76 Lakh tonnes over 1.87 Lakh hectares of land. In Kerala the annual production of jackfruit was 2.63 Lakh tones during 2021-22 contributing to 14.01% of its share to India (APEDA, 2021-22).

The term jackfruit is derived from the Portugese word "Jaca", which in turn is adopted from the word "Chakka" of Malayalam (a regional Indian language) (Pradeepkumar & Kumar, 2008). Jackfruit tree produces the largest tree-borne fruits and is the largest edible fruit in the world and a mature tree can yield anywhere between ten to two hundred fruits annually (Haq, 2006). Jackfruit was considered as heavenly fruit by ancient people in Kerala and is a nutritious fruit, rich in Vitamin A, Vitamin B, Vitamin C, Potassium, β carotene, Calcium, Iron, Proteins and Carbohydrates. The antioxidant (Soong and Barlow, 2004), antibacterial (Khan *et al.*, 2003), antifungal (Trindade *et al.*, 2006) and anti-inflammatory (Wei *et al.*, 2005) effect of the extracts from jackfruit for pharmacological uses are well discussed. In Kerala, jackfruits are classified into two general types; 'Koozha Chakka' and 'Varikka Chakka'. The former has small, fibrous, soft, mushy, but very sweet carpel whereas the latter is more important commercially, with crisp carpel of high quality. The jackfruit has lost its status and now it is one of the under exploited fruits of the state (Samaddar, 1985; Mitra & Mani, 2000). The fruit is frequently referred to as 'poor man's food', as it is cheap and plentiful during the summer season when food is scarce (Jagtap *et al.*, 2010).

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

The jackfruit is a nutritious fruit rich in dietary fiber and it helps to cure ulcers and indigestion; also having anti-cancer properties. Apart from table purpose, the ripen fruits are used for making canned products, nectar, preserve, jam, jelly, squash, fruit bar and candy. In recent years, there has been a growing interest in jackfruit as a sustainable and nutritious food source, particularly as a meat substitute for vegan and vegetarian diets. The fruit's high fiber and protein content, along with its meaty texture, make it a popular ingredient for plant-based meat alternatives, such as jackfruit burgers and tacos.

Jackfruit is an important crop in India and has been cultivated in the country for thousands of years. It is a versatile fruit with a variety of uses, including as a food source, a medicinal plant, and a raw material for various industries. Jackfruit is a staple food in many parts of India, particularly in the southern states such as Kerala and Karnataka. The ripe fruit can be eaten as a sweet, juicy snack, while the unripe fruit is often used as a vegetable in curries and stews. The seeds can also be roasted or boiled and eaten as a nutritious snack. Jackfruit is a highly nutritious fruit, rich in vitamins, minerals, and antioxidants. It is also a good source of dietary fiber and protein, making it a healthy addition to any diet. Jackfruit has been used in traditional Indian medicine for centuries to treat a variety of ailments, including digestive disorders, skin diseases and respiratory problems. The cultivation of Jackfruit provides a valuable source of income for many small-scale farmers in India, particularly in rural areas. The fruit is in high demand both domestically and internationally, and there are many opportunities for value addition through processing and marketing. Jackfruit is a low-maintenance crop that requires minimal inputs such as water and fertilizer, making it a sustainable option for farmers in areas with limited resources. It is also a hardy crop that can grow in a variety of soil types and climatic conditions.

However, despite its potential as a valuable crop, jackfruit farming is still largely traditional and lacks modern technologies and practices. This limits the fruit's productivity and quality, which in turn affects the income and livelihoods of small-scale farmers who rely on jackfruit as a cash crop.

Efforts are being made by governments and international organizations to support jackfruit farmers and to improve production, processing, and marketing of the fruit. For example, in India, the government has launched a National Mission on Bamboo and Rattan, which includes provisions for promoting jackfruit cultivation and value addition. Sensitized growers and entrepreneurs focus more on the development of value-added products. The increasing demand of jackfruit can be regulated by increasing production and also by varietal improvement in species and method of propagation. In spite of its huge production, the utilization as food material is quite negligible, less than 40% and the remaining is going as waste. The traditional method of peeling and coring is done by cutting the fruit into two halves lengthwise using a knife, which is a time-consuming process and causes drudgery. Moreover, the latex of this fruit is also hindering during the separation of the fruit bulb for consumption. The tedium in manual processing is a major reason for the underutilization of the fruit. Thus, effective mechanization in processing is a need of the hour.

Overall, the current situation in jackfruit production is promising, with increasing global demand and growing recognition of the fruit's potential as a sustainable food source. However, there is still a need for greater investment and support for jackfruit farmers to ensure the fruit's long-term sustainability and profitability.

Jackfruit seeds are often discarded as waste, but they are actually a valuable part of the fruit that can be used in a variety of ways. Jackfruit seeds are a good source of protein, dietary fiber, and essential vitamins and minerals such as iron, magnesium, and zinc. Tananuwong *et al.* (2002) reported the chemical compositions of jackfruit seed flour. The major components of the flour were carbohydrates (82.25%), protein (11.17%), lipid (0.99%) and crude fiber (1.67%). They are also low in fat and calories, making them a healthy addition to any diet. Jackfruit seeds can be roasted, boiled or ground into flour and used in a variety of dishes. In some parts of India, they are used as a substitute for lentils or chickpeas in curries and stews. They can also be eaten as a snack after roasting or boiling. They have been used in traditional medicine to treat a variety of ailments, including diarrhea, fever, and skin diseases. They are believed to have anti-inflammatory and antioxidant properties that can help improve overall health. It contains starch called "jackfruit starch" which can be used in the manufacturing of various industrial products such as adhesives, paper, and textiles. Jackfruit seeds are often discarded as waste, but they have the potential to provide a valuable source of income for farmers and entrepreneurs. In recent years, there has been growing interest in jackfruit seeds as a sustainable and nutritious food source, which has led to increased demand and higher prices in markets.

Currently, peeling jackfruit seeds is a laborious and time-consuming task, which limits the amount that can be processed. With a seed peeler, more seeds can be processed in less time, reduce drudgery, increasing the overall yield of valuable jackfruit products. Secondly, a seed peeler can improve the quality of jackfruit products by reducing the risk of contamination during the peeling process. Manual peeling can introduce dirt, bacteria, and other contaminants to the seeds, which can affect their nutritional value and overall quality. In case of seed peeler, it is ensured that the seeds are properly cleaned and sanitized before processing, so that the risk of contamination can be reduced and improving the quality of the final product.

Finally, the development of a seed peeler can create new opportunities for the jackfruit industry. With increased efficiency and improved quality, more products can be produced from jackfruit seeds, which could lead to the development of new markets and increased demand for jackfruit products. This could provide economic benefits for farmers and businesses involved in jackfruit production, as well as contributing to the overall growth of the agricultural sector.

A study was conducted at KCAET, Tavanur during 2018 to develop jackfruit seed coat remover (Anjaly *et al.,* 2021). In the existing model, the peeling was achieved by abrasion of the seeds against the emery coated disc and cylinder. This emery stone was fixed using araldite glue which is not recommended for human consumption. In addition to this, the emery detaches from the disc and gets mixed with the jackfruit seeds when the cylinder is rotated at high speed resulted in poor quality product.

As an attempt to overcome these problems, a study was conducted at KCAET, Tavanur to modify the existing machine using stainless-steel perforated sheet as inner cylinder instead of emery coating as the abrasive material with the following objectives.

1. To study the engineering properties of jackfruit seed.
2. To modify the existing power operated seed coat remover for jackfruit seed.
3. To study the performance of the modified machine in terms of peeling efficiency, seed damage, material loss etc.

REVIEW OF LITERATURE

CHAPTER 2
REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various research workers related to the engineering properties of agricultural produce, study of various peelers, health benefits of jack fruit seed, Jackfruit seed flour, its nutritional composition and development and evaluation of various vegetable peelers.

2.1 Jackfruit (*Artocarpus heterophyllus* L.)

2.1.1 History and Distribution

Jackfruit is indigenous and grows wild in the rainforest of the Western Ghats of India. The name originated from Malayalam name Chakka, other Indian names of the fruit are: Halasu (Kannada), Panasa (Sanskrit and Telugu), Kathal (Hindi), Phanas (Marathi) and Pala (Tamil) (Pradeepkumar & Kumar, 2008). Jackfruit is popularly known as poor man's fruit in the Eastern and Southern parts of India with significant contribution to the low-income families as a good source of vitamins, minerals and calories (Rahman *et al.,* 1995). Nowadays, it's common to see jackfruit trees growing in Bangladesh, Malaysia, Burma, Sri Lanka, Indonesia, the Philippines in the Caribbean islands, the evergreen forest zone of West Africa, Northern Australia, parts of the USA (Florida and California), Brazil, Puerto Rico, and the Pacific Islands, which include Palau, Yap, Pohnpei, Nauru, Tabiteuea in Kirivati, Samoa, and other islands. India's top jackfruit-producing states are Tamil Nadu, Assam, Kerala, and Assam. A total of 1,02,552 acres are used for jackfruit cultivation, of which an estimated 1,00,000 trees are grown in backyards and as an intercrop with other industrial crops. Kerala cultivates jackfruit on the largest scale, with a yield of roughly 348 million fruits on an area of 97,540 acres (APAARI, 2012).

Fig. 2.1 shows that, the cultivated area of jackfruit in Kerala during (2013-14) was 90,225 ha and jackfruit was widely cultivated in Idukki (14636 ha), Kozhikode (9805 ha) and Kannur (8400 ha) districts and stand 1st, 2nd and 3rd positions with16%, 11% and 9% of area, respectively. Gross production of jackfruit in Kerala is 294 million fruits with Idukki district holding the top most position (60 million) followed by Kannur district (27 million) (Table 2.1).

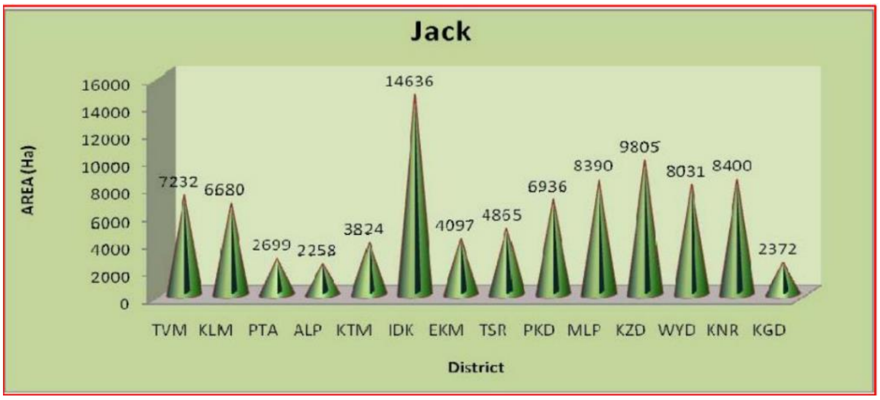


Fig. 2.1 District-wise cultivated area of jackfruit in Kerala (2013-14)

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

Table 2.1 District-wise area and production of jackfruit in Kerala (2013-14)

Sl. No.	Name of district	Area of cultivation (ha)	Production (Million Number)
1	Thiruvananthapuram	7232.43	25.821
2	Kollam	6680.00	23.136
3	Pathanamthitta	2698.54	8.968
4	Alappuzha	2258.3	5.627
5	Kottayam	3824.06	14.728
6	Idukki	14635.92	60.307
7	Ernakulam	4097.46	14.35
8	Thrissur	4864.5	15.636
9	Palakkad	6936.21	22.697
10	Malappuram	8390.12	22.278
11	Kozhikode	9805.43	23.121

12	Wayanad	8030.6	21.275
13	Kannur	8399.59	27.081
14	Kasaragod	2371.79	9.209
	State total	**90224.95**	**294.234**

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

2.1.2 Botanical Aspects

The jackfruit tree is an evergreen with oval-shaped, dark green leaves that is between 10 and 15 metres tall. 3 to 8 months after blossoming, jackfruits reach maturity. The fruit often turns from light green to yellow-brown when it is fully grown. When the fruit is tapped, the closely spaced spines give to light pressure, and the sound is dull and hollow. The yield varies from a few fruits in the first year of bearing to as many as 250 fruits when the plant is 15 years old (Sharma et al., 1997).It is a tree that lives for 60 to 70 years and has sticky white latex in every portion of its fruit. The trunk and primary branches are where the flowering twigs are mostly carried. The monoecious jackfruit tree produces male and female blooms on different branches. The combined fruit can weigh up to 20 kilogrammes. Fruit is the main economic output of trees and is utilised in both the mature and immature stages. (Nachegowda *et al.,* 2014). Each fruit is oblong cylindrical in shape and is 30 – 40cm in length. When ripe they are acid to sweetish in taste.

The lower fleshy edible section of the jackfruit is known as the bulb. The middle-fused region, which forms the rind of the syncarp, and the higher free and horny non-edible region are both referred to as the spikes. All fruit portions, save the spiky outer bark, are edible (Prakash *et al*., 2009).

2.1.3 Varieties

Elevitch and Manner (2006) asserted that the size and structure of the tree, the shape and colour of the leaves, the age at which the fruit begins to ripen, and the size, shape, and texture of the edible pulp all contribute to species variation. The two most common jackfruit types in Kerala are koozha and varikka. Koozha is the name for a type of jackfruit with a thin, fibrous, and mushy edible pulp that is highly delicious and emits a strong aroma. However, the pulp of varikka is less fragrant and is thick, hard, and crisp. The primary jackfruit types in Kerala are Thamara chakka, Nadavalamvarikka, Vakathanamvarikka, Muttomvarikka, Aathimathuramkoozha, Ceylon varikka, and Thenga varikka. The key types Konkan prolific, Ceylon jack, Hybrid jack, Burliar-1, PLR-1, and PPI-1 were all introduced by different organisations (Priya *et al.,* 2014).

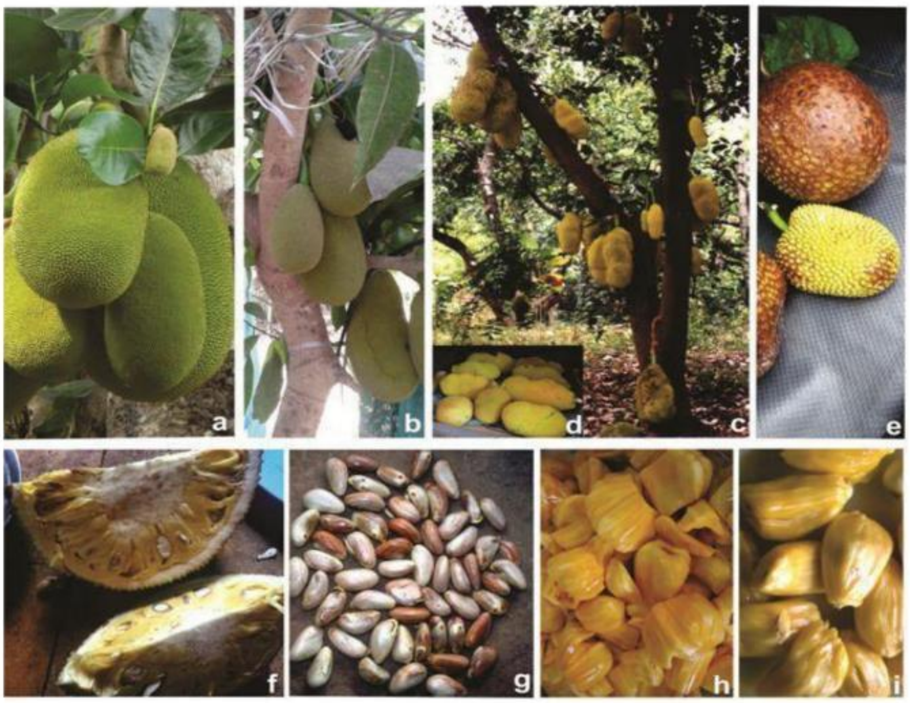


Fig. 2.2: Jackfruit a,b) jackfruit with varying sizes; c) tree bearing fruits; d) fruits plucked; e) small type of jackfruit; f) jackfruit cut opened; g) jackfruit seeds; h) opened jackfruit bulbs; i) jack fruit bulb

2.1.4 Propagation

Although jackfruit is frequently grown through seeds, vegetative propagation techniques are preferable due to their limited viability and lack of true-to-type characteristics. The percentage of germination and seedling growth can be increased by soaking seeds in 1-naphthaleneacetic acid (25 ppm) for 24 hours. When etiolated shoots are ringed and treated with indole-3-butyric acid (at a concentration of 3000 ppm) and ferulic acid (at a concentration of 2000 ppm), cutting is another technique with a high success rate of 90% (Dhua *et al.,* 1983). When treated with IBA, air layering is thought to be a better technique with a 100% rooting rate. In Kerala, epicotyl grafting under mist with 3- to 4-month-old scion and 5- to 10-day-old stocks had an 80-90% success rate. Any of these techniques could be a good choice for jackfruit propagation, depending on the grower's particular requirements. (Jose & Valsalakumari, 1991)

2.1.5 Nutritional Composition

The chemical makeup of bulbs was investigated by Jagadeesh *et al.*,(2007). According to the study, several species of jackfruit have bulbs that are total soluble solids (TSS), acidic, sweet, starchy, and carotenoid-rich. Additionally, it is an abundant source of vitamins A, B complex, C, potassium, calcium, iron, proteins, and carbs.

Jackfruits are very nutritious and therapeutic. It can improve digestion, boost energy, lower blood pressure, control asthma, strengthen bones, avoid anaemia, and keep the thyroid functioning normally. It can also assist to maintain a healthy immune system and prevent cancer as per Priya *et al.,* (2014).

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

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

Vitamins

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

Minerals

Total minerals	0.90	0.87-0.90	0.90-1.20
Calcium (mg)	30.00-73.20	20.00-37.00	50.00
Magnesium (mg)	-	27.00	54.00
Phosphorus (mg)	20.00-57.20	38.00-41.00	38.00-97.00

Potassium (mg)	287.00-323.00	191.00-407.00	246.00
Sodium (mg)	3.00-35.00	2.00-41.00	63.20
Iron (mg)	0.40-1.90	0.50-1.10	1.50

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

2.1.6 Harvesting

Fruits in Asia typically ripen from March through June, April through September, or June through August, depending on the climatic zone, and for some off-season crops from September through December (Morton, 1987). Jackfruits reach maturity 3 to 8 months after blossoming.

When fully developed, the fruit often turns from light green to yellow-brown, has tightly spaced spines that yield to mild pressure, and makes a dull hollow sound when tapped (Sharma *et al.,* 1997).

2.1.7 Post harvest utility

Less than 40% of the jackfruit is used as food, and the remainder is wasted due to a laborious and time-consuming manual processing process. Jackfruit is typically consumed in its raw and refined forms. The main cause of the underutilised fruit is because the latex of this fruit makes it difficult to separate the fruit bulbs for ingestion.

Jackfruit is a popular vegetable that is available on the market from spring through summer. Since jackfruit has a storage life of just around 4-5 days at room temperature (25–35°C), it must be consumed or sold right away. It can be kept for up to six weeks in cold storage at temperatures between 11.1 and 12.8 °C and humidity levels between 85 and 90% (Bose *et al.,* 2003). Fruit that is still immature is boiled, fried, or roasted. Due to its distinctive flavour, the ripe fruit is disliked by many people; however, the seed is roasted and utilised in numerous culinary recipes (Siddappa & Bhatia, 1955). Still-developing fruit is boiled, fried, or roasted. The ripe fruit is hated by many people due to its peculiar flavour, however the seed is roasted and used in a variety of culinary preparations (Bhatia *et al.,* 1956a; Bhatia *et al.,* 1956b; Teaotia and Awasthi, 1968). Shruti (2005) developed diversified food products namely clarified juice, jackfruit nectar and jackfruit bars by applying innovative and indigenous technologies and explored the possibility of by-products recovery (pectin and starch) from the waste generated after jackfruit processing. A suitable preparation technique of quality jackfruit chips and their good packaging was reported by Molla *et al.,* (2008).

2.2 Jackfruit Seeds

The proper germination of seeds is essential to agricultural productivity, food security, plant restoration, and sustainability. In a greenhouse experiment, the germination and seedling performance of five jackfruit ethno-varieties were assessed. among the ethno-varieties, there are differences in the length, width, and weight of the seeds, with the soft variety having larger fresh and dry weights. The soft ethno-variety had the highest root: shoot ratio and grew more quickly, whereas the white ethno-variety had the highest pre-emergence mortality but the slowest germination time. The majority of attributes saw their best growth between 6 and 7 weeks after sowing, which can help choose when to transplant seedlings (Nantongo *et al.,* 2022).

Jackfruit seeds might be thought of as a potential functional food ingredient because they have significant nutritional advantages. However, more information regarding the production of jackfruit seeds for commercial purposes and their use in food products has to be investigated. Products having jackfruit seed flour in them have better nutraceutical appeal, which raises consumer acceptance. Additionally, it demonstrates how jackfruit seeds are valued and their effects on the various features of the products' value-added components (Waghmare *et al.,* 2019). Despite being plentiful and comprising 10% to 15% of the weight of the fruit, jackfruit seeds are frequently disregarded for their nutritional value

(Hossain, 2004). The seeds are gathered, dried, and kept in South India for subsequent use. However, because of problems with processing and storage, a sizable volume of seeds are wasted every year. While their shelf-life is only one month due to their perishable nature, roasting and powdering the seeds can increase their usefulness. A cheap substitute flour for wheat and other flours is jackfruit seed powder, which is used in baked foods.

Some regions of India consume the seeds boiled or roasted, and they supplement potatoes (Banarjee & Datta, 2015). Jackfruit seeds could be a solution to malnutrition in India since it's an economical protein source. The seeds are increasingly in demand due to a growing awareness of the diet-disease connection. They are regarded as a functional food ingredient since they offer extra physiological advantages in addition to essential nutrition (Chowdary *et al*., 2012).

By examining how drying and frying operations affect jackfruit seeds, Akmeemana *et al*., (2022) created an easy-to-cook jackfruit seed product. Jackfruit seeds were used to create four alternative formulations using a two-factor factorial design, with soaking in water and case hardening (drying and frying) as the variables. All 4 samples underwent sensory evaluation using a 5-point hedonic scale with a 5% level of significance, and their cooking times were noted. Two soaked samples (dry, soaked jackfruit seed sample and fried, soaked jackfruit seed sample) demonstrated superior sensory acceptance than the unsoaked samples, according to the results of the sensory evaluation and cooking time determination. For samples that had been soaked, the proximate composition, phytochemical content, water and oil holding capabilities, and colorimetric values were assessed. As a result, there was a significant difference between the fried and dried jackfruit seed samples in terms of ash, fat, crude protein, calcium, magnesium, potassium, and phenolic content (p 0.05), but not moisture content or titratable acidity ($p > 0.05$). The soaking process dramatically decreased the amount of time jackfruit seeds needed to cook. The best sensory treatment included jackfruit seeds that had been dried and then soaked.

The capacity of plant seeds to germinate, as well as seedling survival and vigour, is a crucial aspect of their performance. Five jackfruit ethno-varieties' (farmers' understanding and management of infra-specific diversity) seed properties were evaluated. The survival, emergence, and germination rates of seeds were examined in a greenhouse experiment. The length of the seeds varied amongst distinct ethno-varieties ($F (4,145) = 6.31$, p 0.001). Seeds from white, orange, or yellow ethno-varieties had the biggest differences. Additionally, there was a small variation in width between ethno-varieties ($F (4,145) = 3.29$, p 0.05). In comparison to the other ethno-varieties, the soft ethno-variety's average fresh and dry weights tended to be greater in seeds. The white ethno-variety demonstrated the highest pre-emergence mortality but the shortest germination time when it came to differences in seed survival and germination rate among ethno-varieties. The soft ethno-variety demonstrated the highest root: shoot ratio over the course of the six-week germination period, but it also grew more quickly than any other ethno-variety. Potential evolutionary evidence of restrictions on seed size, germination, and seedling vigour exists. Most features showed their best growth between 6 and 7 weeks after seeding, which can help determine how long seedlings should stay in their containers before being transplanted to the field. In order to distinguish the growth features among the ethno-varieties more clearly, additional progeny testing on these provenances should be conducted in the field over a longer period of time (Nantongo *et al*., 2022).

In Brazil, jackfruit seeds (Artocarpus heterophyllus Lam.) are a common source of garbage and may include the aroma of chocolate. Using a standard Brazilian cocoa powder as a comparison, Spada *et al.,* (2021) analysed the fragrance components in flours made from roasted jackfruit seeds. Before being dried and roasted, jackfruit seeds were either left untreated, acidified, or fermented. Gas chromatography mass spectrometry was used to evaluate the volatiles after they had been extracted using solid phase micro extraction or solid phase extraction. GC-Olfactometry was used to determine which volatiles were the most odour-active. However, the jackfruit seeds produced much more pyrazines, some of which were responsible for the distinctive earthy "roasted jackfruit seed" aroma. The majority of the compounds known to be odour active character impact chemicals in cocoa goods were also detected in the jackfruit seed flours. The sample that had been fermented exhibited an olfactory profile that was most like cocoa powder.

2.2.1 Jackfruit seed flour

In place of wheat flour, jackfruit seed flour can be used to make dishes like vada, chapatti, cake, buttered biscuits, bread, pancakes, and noodles. Industry standards were followed in the processing of these products. Organoleptic aspects of the produced items, such as colour, texture, appearance, flavour, taste, and general acceptability, were found to be quite satisfactory. It is common knowledge that processing seeds enhances the flavour, nutritional value, and digestibility of food. The seeds can be converted into intermediate products, such as flour, that can be stored for a long time. In order to create unique dishes like cake, bread, and biscuits while keeping the functional and sensory qualities of the finished product, this flour may also be used alone or in conjunction with other grain flours.

The confectionery and pastry industries frequently use wheat flour as a main ingredient. The price of wheat flour is rising daily. Jackfruit seed flour can be used as an alternative in baking and bread making. Jackfruit seed flour is rich in minerals, protein, and carbohydrates. There are anticancer, antispasmodic, antiulcer, and antihypertensive properties. It can be used in baked goods including cakes, biscuits, energy drinks, and other bakery items as a gluten-free substitute for maida. Jackfruit seeds can be eaten roasted or boiled, and their nutritional makeup is similar to that of cereals. The seeds of jackfruit, which are extremely seasonal and have a short shelf life, are wasted when there is a seasonal excess.

Well matured and just matured ripe jackfruit

↓

Slicing, peeling and extracting bulbs

↓

Deseeding bulbs

↓

Manual cleaning of jack seeds

↓

Seeds were soaking in 3% sodium hydroxide solution for 4-5 min (lye peeling)

↓

Slicing into thin chips

↓

Drying @ 60-70° C

↓

Blending in a hammer mill/Mixie

↓

Jackfruit seed flour and sieving

↓

Packing of sieved flour and storing

Fig. 2.4. Flow diagram for the processing of Jackfruit seed into flour

Source: Satheesh *et al.,* (2019)

Therefore, the seed flour can be a different intermediate product that can be used to add value to other grain flours while also blending with them without changing the final product's functional or sensory characteristics. Furthermore, it has been discovered that adding seed flour to goods that are deep-fried in fat significantly reduces the absorption of fat. One jackfruit seed is contained in a white aril that is surrounded by a slender brown spermoderm and a fleshy white cotyledon. Jackfruit cotyledons contain a considerable amount of protein and carbohydrates.

Additionally, jackfruit seed flour is used to add value to both traditional and novel products. The powder made from jackfruit seed contains manganese and magnesium. Jackfruit seeds contain salt, calcium, potassium, fibre, and potassium. In recent years, scientists have started studying jackfruit seeds as a potential alternative source of protein and carbs for use in industry. Products made with jackfruit seed flour are more nutritionally appealing, which increases consumer acceptance.

The ripe fruits are eaten or used to make candies and snacks. The seeds can be converted into intermediate products, such as flour, that can be stored for a long time. Without sacrificing the end product's functional and sensory properties, this flour may also be used alone or in conjunction with other grain flours to create novel culinary products including cake, bread, and biscuits. The confectionery and pastry industries frequently use wheat flour as a main ingredient. The price of wheat flour is rising daily. Jackfruit seed flour can be used as an alternative in baking and bread making. Instead of throwing away jackfruit seeds after harvest, jackfruit seed flour can be combined with wheat flour to create nutritious bread products.

The moisture content of jackfruit seed flour, as determined by the Kjeldahal method, was 9.97%; the crude protein content, as determined by the solvent extraction method, was 12.1%; the crude fat, as determined by the solvent extraction method, was 3.12%; and the ash, as determined by the proximate analysis, was 1.23% (Satheesh *et al.,* 2019).

2.2.1.1 Functional properties of jackfruit seed flour

Royees and Pandey (2022) studied the functional properties as follows:

- The ability of flour to bind with water when water is limited is referred to as water absorption capacity. The established water absorption capacity was 2.8 g/ml. An essential processing factor that affects viscosity is water absorption capacity. Additionally essential for product bulking, homogeneity, and baking applications is water absorption capability. The result shows that flour has a potent capacity to bind water.

- Oil absorption, whose value ranges from 0.97g/ml to 2.8g/ml, is a crucial component in the formulation of food products since it influences flavour and mouth feel. The value for flour made from roasted jackfruit seeds ranges from 1.5 g/ml to 3.0 g/ml. This demonstrates that jackfruit seed flour has a high rate of flavour retention, indicating that it can be useful in food systems like compositions of ground meat.
- Bulk density is determined by sample particle size. The bulk density of the uncooked jackfruit seed flour was 0.61g/ml. Bulk density is a way to gauge how heavy a sample of flour is. Roasted jackfruit seed flour has a density of 0.256–0.327 g/ml. It is essential for establishing packaging requirements, material handling, and application in the wet processing of the food business. Since flours with high bulk densities are frequently used as thickeners in culinary items, the jackfruit seed flour may be used as one.
- The seed flour samples' swelling powers ranged from 6.58% to 9.46%. Food eating quality and water-swollen starch granule retention are related. Swelling power is a parameter for swollen starch granules.

2.2.1.2 Nutritional composition of jackfruit seed flour

The jackfruit seed's potential as a food source and antioxidant has not yet been properly investigated. The seeds of the jackfruit are a good source of carbohydrates, fibre, and protein. According to research, the carbohydrate content of various jackfruit seed variants can range from 37.4% to 42.5%. Jackfruit seeds can range in protein content from 5.3% to 6.8%. Other nutrients found in abundance in jackfruit include nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, and copper. On a dry basis, jackfruit seeds have a protein content of 14%, an 80% carbohydrate content, 2% ash, and 1% fat. Seed flour has a calorific value of 356 kcal/100 g (Royees & Pandey, 2022).

The presence of pectin compounds, vitamins A, B, and C, and pectin compounds aid in blood purification and pancreatic health maintenance. One kilogramme of seeds typically contains 1478 mg of potassium, 10 mg of copper, 3087 mg of calcium, 130 mg of iron, and 61 mg of sodium. The climate and variety of the seeds that were grown, however, affect the nutritional makeup. The seed contains a lot of flavonoids and isoterpenes that improve its nutritional profile. Phenols, saponins, alkaloids, tannins, steroids, etc. are all present. It also contains a lot of riboflavin (vitamin B2). Fresh seeds are a significant source of ascorbic acid, phenolic compounds, and antioxidant activity, which together account for nearly 70% of all antioxidant activity. Sulphur and its compounds, which are found in jackfruit seeds, are what give them their antibacterial properties (Royees & Pandey, 2022).

2.2.1.3 Mineral composition of jackfruit seed flour

Minerals are inorganic substances that are present in all of the body's tissues and fluids. Despite the fact that they don't generate energy, they are essential for the body's many processes. For glucose metabolism, bone and tooth growth, enzyme activity, and the preservation of the body's acid-alkaline balance, calcium, phosphorus, and magnesium are necessary. The formation of blood requires the presence of iron. Cu helps in iron metabolism. Over 100 enzymes involved in energy metabolism require zinc, while a few enzymes use manganese as a cofactor.

Table 2.3: Mineral Composition of jackfruit seed flour in mg/100 gm

Component	Amount (mg/100 gm)
Calcium	115.85
Magnesium	96.75
Potassium	705.71
Phosphorus	0.13-0.23
Iron	0.002-1.2
Lithium	0.05
Sodium	38.41
Ammonium	12.33

Source : Royees and Pandey (2022)

In comparison to the other minerals, potassium (705.71 mg/100 gm), calcium (115.85 mg/100 gm), and magnesium (96.75 mg/100 gm) are substantially more abundant. Here, a sodium to potassium ratio less than one may be advised by medical professionals to lower blood pressure. Given that it contains a lot of calcium, it may also be beneficial for the growth of bones. Processing has an impact on the jackfruit seed flour's chemical makeup. The protein content of heated jackfruit seed flour rose the most (61%), in comparison to raw jackfruit seed flour (Royees & Pandey, 2022).

Protein denaturation, which is followed by protein aggregation, either soluble or insoluble protein complexes, may be the cause of the increase in protein content observed in jackfruit seeds after heat treatment. Protein can be precipitated using a variety of techniques, including flocculation, ultrafiltration, thermo coagulation (temperature action), auto coagulation (fermentation), flocculation, and organic solvent extraction. Nevertheless, the germination procedure had little impact on protein content when compared to raw jackfruit seed flour.

2.2.1.4 Health Benefits

Jackfruit seeds have an oval or spherical form, are brown in colour, 2-4 cm long, and are 1.5–2.5 cm thick. 100 to 150 seeds, or 10 to 15 percent of the weight of the fruit, are present in each fruit. Ripe fruit seeds are collected, carefully dried in the sun, and kept for later use. Nevertheless, a significant amount of seeds are lost each year due to ignorance of their processing and storage characteristics, as well as their nutritional and bioactive profiles. Storage of seeds in a cool, humid atmosphere can extend their shelf life by an additional 30-35 days (Royees & Pandey, 2022). Utilising jackfruit seeds as a source of protein can help people with deficient conditions like PEM.

Consuming jackfruit seeds is very advantageous because they aid in digestion, have anti-carcinogenic qualities, and shield against wrinkles. The isoflavones, lignans, and saponins found in jackfruit seeds provide a variety of health advantages. The seeds contain sulphur and sulphur compounds, which have antibacterial effects. Jackfruit seeds that had been sown demonstrated antifungal, antibacterial, and immune-modulating qualities. Therefore, seeds can be used to make medicinal goods that will increase the potency of the medicine. When employed as a tool, jacalin, a significant lectin found in seeds, assesses an HIV-positive person's immunity. Jackfruit seeds not only promote healthy blood circulation and digestion but also optimal hair development. high starch content, low calcium and iron content, and excellent source of vitamin B2. Due to their high magnesium content, which is a vital mineral for calcium absorption, these seeds are also beneficial for maintaining bone health and preventing diseases like osteoporosis.

Seed flour is very important for usage in marketing and the food production business due to its therapeutic properties and potent components. Additionally, seeds are eaten in place of potatoes. By adding the seed flour to meal preparations, these can be used as a source of protein. The roasted seeds are a common ingredient in the creation of many foods nowadays. As a replacement for cocoa powder, roasted seeds are frequently added to cappuccinos to meet expanding demand. In addition to roasting, the seeds can be used to make tomato sauces, curries, syrups, and brine dishes. They can also be cooked, germinated, or ground into flour.

2.3 Engineering Properties

Engineering properties of agricultural produce are useful in the design and development of various processing machineries. Shidenur *et al.,* (2017) identified various jackfruit (*Artocarpus Heterophyllus* L.) engineering characteristics that are important for the development of peelers and corers. Jackfruit measurements including length, diameter, weight, rind thickness, core length, and diameter ranged from 26.52 to 55.81 cm, 18.23 to 27.8 cm, 5.35 to 16.65 kg, 1.59 to 2.42 cm, 20.23 to 48.06 cm, and 3.99 to 9.72 cm, respectively. Using the universal testing machine and a specially built cutting probe, the cutting strength of peeled jackfruit was evaluated. The measured cutting strengths of peeled jackfruit ranged from 2.5 to 3.5 kN, with an average value of 2.96 0.42 kN.

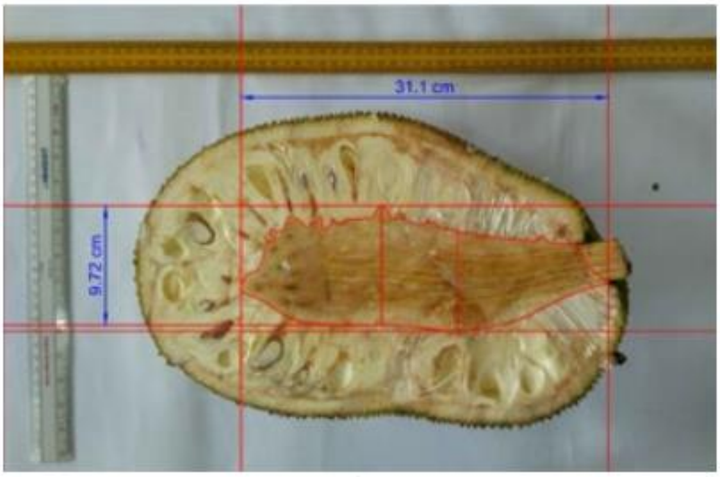


Fig. 2.3: Measurement of length and diameter of jackfruit core

Source: Shidenur (2017)

Table 2.4 Physical properties of Jackfruit

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

Source: Shidenur (2017)

2.3.1 Mechanical properties

2.3.1.1 Cutting force

Cutting strength is a critical mechanical characteristic that is frequently used to assess the durability and toughness of materials and tissues in the presence of cutting and coring forces. The creation of specialised equipment has benefited from numerous research that looked at the amount of force needed to chop different fruits. Additionally, a number of researchers have examined how cutting strength is determined in distinct produce types.

Ohwovoriole *et al.,*(1988) measured the cutting strength of the unpeeled and peeled cassava tuber to estimate the required cutting force. A cutting tool (a 1.5 mm thick piece of metal with a sharpened edge at a 300-degree angle) was inserted between the universal testing machine's plungers during this test. The device compresses the samples at a rate of 20 mm/min, and the information obtained was used to create a cassava peeler. The study by Visvanathan *et al.,* (1996) examined the cutting strength of cassava tubers. According to the study, the amount of force used to cut a cassava tuber varies on the angle and speed of the knife. At a knife bevel angle of 30-45, knife velocity of around 2.5 m/s, and shear angle of 63-75, the specific cutting energy for cassava tubers was found to be at a minimum (6.5 kJ/m^2). To create a peeling machine, Emadi (2005) examined the mechanical characteristics of many types of pumpkin and melon fruit. For testing the cutting force of a product in three states—unpeeled, flesh, and skin—a cutting indentor, cutter device, and holder for unpeeled and skin sample were designed and constructed. The cutting indentor was designed and built using stainless steel with a 1.5 mm thick edge that had been sharpened (30 included angle). Using a cutting tool, samples were made from the various melon and pumpkin pieces and stored in the holder. The universal testing machine (UTM), which subjects a load at a speed of 20 mm/min, has the cutting indentor fixed to it. The study reveals that, the cutting strength of unpeeled sample of Jarrahdale, Butternut, Jap, Rock melon, Honeydew and Watermelon was 5.15, 20.48, 10.99, 12.19, 9.55 and 10.13 N respectively whereas in skin samples, it was found as 2.82, 17.31, 9.41, 12.65, 9.96 and 10.16 N respectively. According to Ambrish (2005), the greatest force needed to chop anola fruits ranged from 15.25 kg for the NA-7 types along the stem end side to 7.43 kg for the Kanchan variety along the axis of fruit. At three different sites, Shamsudin *et al.,* (2009) conducted research on the firmness of pineapple fruit. Using the Instron Universal Testing Machine (UTM), a cylindrical die with a 6 mm diameter was used to gauge the fruit's firmness. The outcome showed that, due to the ripening process and storage period, force dropped with maturity stage from 74.79-42.93 N (top position), 62.56-37.20 N (middle position), and 57.14-36.04 N (bottom position).

2.4 Mechanical peelers

Peeling is the primary unit operation in processing of many fruits and vegetables to remove unwanted or inedible material and to improve appearance of final product. Main consideration is to minimize cost by removing as little of the underlying food as possible and reducing energy, labour and material costs to a minimum. The peeled surface should be clean and undamaged. There are five main methods of peeling viz. knife peeling, abrasion peeling, flame peeling, flash steam peeling, and lye peeling (Sudheer & Indhira, 2007). Numerous peelers have been developed by different academicians for different peeling purposes. Here are some of them.

In order to ascertain the engineering characteristics of garlic (GG-4) that are important for the creation of a garlic peeler, Singh *et al.,* (2022) conducted a study. Both the garlic bulb and the garlic clove had their engineering characteristics tested at a wet basis moisture level of 41.69%. The design and evaluation of rotary disc type garlic clove peeling machines was based on the engineering characteristics of garlic and the aforementioned problems. After being put to the test, it was discovered that the recommended rotary disc type garlic peeler had a peeling effectiveness of 89.43%. Additionally, it was revealed that the peeling machine cost $137 in total. The surface shearing principle underlies the operation of the newly invented rotary disc type garlic clove peeler, which is composed of simple parts. The high-quality rubber-coated machine disc moves against a stationary cylinder, causing frictional and shearing forces that cause the garlic to be peeled off.

Many different cassava products are manufactured in Ghana, but many of them necessitate peeling, which is currently done manually and requires a lot of time and work. To solve this problem, a motorised cassava peeler with four different lining materials—concrete, metal, rubber, and wood—was created and tested on the Asi-Abayiwa and Dabon kinds of native cassava. The peeler's capacity, peel removal effectiveness, % flesh loss, and batch loading weight were all calculated. The peeler was discovered to have a 6 kg batch loading weight, a 71.8% average peel removal efficiency, a 28.83% average meat loss, and a 157–1439 kg/h peeling capacity range for all lining materials. According to the investigation, the peeler could successfully carry out its intended function, and the rubber and wood lining materials showed especially strong peeling capacity. Future research should concentrate on determining the cassava cultivars that respond the best to mechanical peeling (Amanor & Bobobee, 2021).

With 263,170 MT being produced from an area of 77,610 hectares, India is in charge of generating half of all ginger in the globe. Ginger peeling requires a lot of effort and time, and is often accomplished with a knife or by rubbing the ginger on bamboo mats or gunny bags to hasten the drying process. To prevent material loss during peeling, certain precautions must be taken. To solve this problem, a straightforward hand-operated ginger peeler and polisher that uses abrasion technology was created for use on farms. The machine includes a perforated drum that is manually rotated at 45–50 rpm and is lined with emery strips spaced 25 mm apart. During testing, it was discovered that the device achieved 74–81% peeling efficiency with a batch of 5 kg in 8–12 minutes, with a material loss of roughly 2.5%–3.8%. The machine's actual production was discovered to be between 25 and 30 kg per hour, which was higher than the manual and gunny bag peeling rates of 30 and 50 kg per day, respectively. Due to friction and abrasion, the machine was also useful for polishing dried rhizomes, leaving a smooth surface. The machine's polishing capability was determined to be 50–60 kg/h, and its estimated price is Rs 3000 (Jain *et al.,* 2007).

The physico-chemical characteristics of pineapples of the Giant Kew variety were researched by Bhore *et al.,* in 2017. When the pineapple's dimensions were measured, it was discovered to be 130 mm in length, 95.6 mm in width, and 86.56 mm in thickness, with an average weight of 1375.46 g. The moisture level of the pulp and peel, respectively, was 78.55% (wet basis) and 84.99% (wet basis). The pineapple's edible section, 59.74-60.04% of the peel, and 20.01-20.23% of the crown were all present. As opposed to the real density, which was 930 kg/$m^3$19.23 and 880 kg/m^3 11.30, the bulk density with and without a crown was 152 kg/m^3 8.00 and 122 kg/m^3 4.00, respectively. The porosity was 86.33% 1.59 and 81.33% 2.50, respectively, with and without the crown. The pulp contained more soluble particles and had a higher pH than the peel. The average values of reducing and non-reducing sugars were 7.15 % and 6.0 %, respectively, while the titrable acidity was 2.03 %. 19.81 mg of ascorbic acid were present per 100 grams. Based on their diameter, the pineapples were divided into three categories and peelers were created for each group. According to the examination of the peeler's performance, 56.13% of the pulp was extracted from pineapples of Grade A, 56.45% from those of Grade B, and 56.8% from those of Grade C.

The pedal-operated potato peeler created at CIAE, Bhopal, has undergone numerous revisions and refinements that have resulted in material and fabrication time reductions, ease of maintenance, user friendliness, and even just reliable performance. The water spray pipe assembly, hinged top cover, potato feeding gate, and chain drive assembly have all been improved. The improvements were made to increase the peeler's effectiveness, reliability, and ease of maintenance (Saxena *et al.,* 2016).

A continuous beetroot peeler with 10 carborundum-coated abrasive rollers divided into two pairs of 5 rollers was created by Gobashy *et al.*, in 2003. The items could be scraped or peeled evenly since the left-hand rollers rotated anticlockwise and the right-hand rollers turned in the opposite direction. A frequency-controlled conveyor screw was used to move the product through the device. According to the needs, the peeling time might be continuously modified.

An automated cassava peeling machine featuring a peeling tool with a knife edge was developed by O.J. Olukunle*et al.,* (2012). The peeling tool is a revolving cylindrical drum with peeling blades that are auger-likely soldered onto it. The equipment is supported by a frame. Additionally, a metal stripe is fastened in between the rows of blades to improve the transport of the tuber when it is in use. The barrel is propelled through an open shaft by an electric motor and belt-pulley system. The tubers will naturally lie horizontally on the blades thanks to the hopper's design. With very little clearance, the peeling blades on the hollow cylinder peel the cassava tuber up against an adjustable, sharpened blade soldered to the body. Although there isn't enough room for the cassava tuber to fit through, there is enough room for the peel to come off and leave the machine.

Raw mangoes are rotated in a closed cylinder against sharp projections on the inner surface in order to be peeled using a motorised peeler designed by Mandher and Senthil Kumaran (1995).

2.5 Design Expert Software

Software called Design Expert was developed by the State Ease. This was first made available in 1996 to assist with the execution of experimental designs, such as figuring out the best preparation formula. In addition to optimisation, this software can understand the experimental variables. Depending on the experimental design to be used, there are three options for research directions in software. Options include screening, characterising, and optimising. The least quantity of information is provided yet the least amount of run is needed for screening. The number of experiments known as a run must be performed in accordance with the chosen experimental design.

If there are more than six potential causes, but it is unclear which one will actually have an impact, screening is used. Several significant factors were identified utilising only two levels of each component and main effect estimates (interaction was not present). Follow-up with the second DOE is necessary in order to estimate interactions and future requirements. Characterization yields more information but requires more runs per factor. used with a small number of factors (<10). Identify the elements that significantly affect the reaction, such as the interactions (fit a two-factor interaction model) between them. If the components are reduced, think about introducing a midpoint to this design to identify non-linear interactions. It can be used to determine a factor setting that maximises or minimises response when no curves are observed, given the midway.

The greatest information will be provided via optimisation, but it will also take the most runs per element. After reducing down the list of elements (>6) that are known to be significant and whose optimum likelihood is in the area being tested, optimisation is applied. Useful for locating factors settings that either maximise or minimise the response of one of the three experimental design options—factorial/response surface, mixed, or combined—each of which contains three technique options (Sopyan *et al.,* 2022).

2.5.1 Response Surface Methodology

RSM is a method that is frequently employed to optimise a variety of processes. The state-of-the-art RSM applications in the formulation, extraction, drying, blanching, enzymatic hydrolysis, generation of microbial metabolites, and clarifying are presented in this review. The full factorial design (FFD), the Box-Behnken design (BBD), and the central composite design (CCD) are three different designs that are explained along with the fundamentals of RSM. Additionally, this work includes a thorough analysis of recent RSM literature that has been written about several food processing industries and evaluates its RSM elements, which are summarised in tables. Finally, the difficulties and potential uses of this statistical technique in the processes of the food business are examined. It was concluded that the successful implementation of RSM is substantially influenced by the suitable selection of the RSM design, independent variables (screening), and levels of the factors. Furthermore, it is critical to assess the reliability of the ideal conditions anticipated by RSM (Yolmeh *et al.,* 2017). The food industry aims to increase process efficiency and system performance without raising costs or waiting times. The basic goal of "optimisation," a term that has been frequently used, is to identify a state that produces the optimum results for a system (Baş & Boyac, 2007). Previously, optimisation in food processes has been carried out by examining the impact of a single parameter change on a response while maintaining a constant level in all other parameters (Bezerra *et al.,* 2008). The interdependent effects between the variables, which are not taken into account, and the lack of an explanation of the full impact of the factors on the answer are the key drawbacks of this approach. Additionally, this approach calls for more trials to be run, which adds to the research's cost and duration (Baş & Boyac, 2007; Bezerra *et al.,* 2008). Optimisation studies can be carried out utilising multivariate statistical techniques to address this issue. The most common multivariate statistical method, known as Response Surface Methodology (RSM), has been applied to the optimisation of food processing (Baş & Boyac, 2007). In order to make statistical predictions, a data set's behaviour must be depicted using a polynomial model, and RSM is a collection of statistical and mathematical methodologies. The method is helpful for processes where a response or responses are impacted by a number of variables in terms of optimisation, design, development, and improvement (Ghorbannezhad *et al.,* 2016; Kaushik *et al.,* 2006).

The ideal experimental design must be chosen in order to specify which treatments should be carried out in the experimental region under study before applying the RSM approach. Three-level factorial, central composite, and Box-Behnken experimental designs for quadratic response surfaces should be used for this purpose (Bruns *et al.,* 2006).

The Box-Wilson Methodology is another name for the technique called response surface methodology (RSM). Responses from the surface methodology are a combination of statistical and mathematical methods that are useful for problem modelling and analysis where multiple variables affect the response (Montgomery, 2017). The input data that affect a response or outcome variable (output) are linked together using the response surface methodology. If an area with the best reaction is identified, a model is built to link to that region so that the study may be done to locate the best location. According to the protocol, RSM use must be done in the correct order. Equation (1) is employed when a physical event is distant from its ideal state.

y = β0+β1x1+β2x2+…+βkxk+ε … *… 2.1.*

The optimization process with RSM can be seen in fig. 2.5.

A multivariate regression model with two independent variables is represented by equation 2.1. The regressor or predictor variable is the name given to this independent variable. A fixed intercept value is 0 (zero). A partial regression coefficient of 1 and 2 quantifies the change in y for each change in x1 units and the change in y for each change in x units 2, respectively. Through the optimisation process, this equation model will help researchers get closer to the ideal region. The second model, or equation 2.2, is applied after the optimal region has been identified.

y = β0+β1x1+β2x2+β11x12+β22x22+β12x1x2+ε … *...2.2*

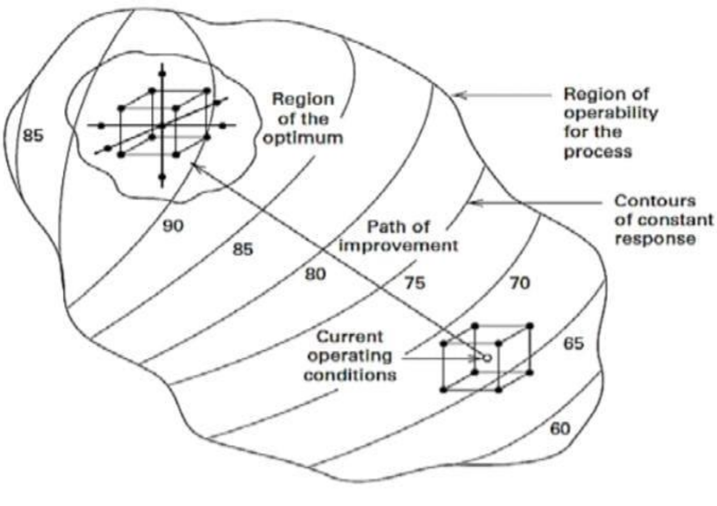


Fig. 2.5 Optimisation process with RSM

Source: Montgomery, 2017

To find the optimum position, the optimisation stage is proceeded by analysing the response surface. An appropriate response surface was used to conduct the analyses. This matched surface analysis will be comparable to the actual system if the matched surface is an estimate of the true response function. If the experimental design used to gather the data adopts an acceptable experimental design, the parameters of the model can be estimated efficiently.

The design of the response surface was created to go with the response surface. For each model, matching employs a different design. There are two designs in RSM: the Box-Bhenken Design and the Central Composite Design (CCD).

2.5.1.1 Central composite design (CCD)

Because the optimisation and ideal location are unknown in RSM, central composite design is used in the optimisation process to roughly establish the optimal direction. Additionally, CCD has rotatability, which means that doing this will result in (y (x)) being the same at point x, which is at the same distance. Based on the test limit values assigned to each research factor, the test points in the CCD are determined. An appropriate mathematical model is used to model the response data. There are various models in CCD, including mean, linear, quadratic, 2FI, and cubic. The selection criteria for the response model are the same as those used to choose models for mixture designs. The value desirability resulting allows for the determination of the optimal point. Desirability demonstrates how content or how close to the ideal one is. The expected value is a value with a desirability near to 1. The ideal point is one that either has a high level of attractiveness or is very near to 1 (Montgomery, 2017).

2.5.1.2 Box-Bhenken design (BBD)

Three independent variables are optimised using the Box-Bhenken Design (BBD). The Distinction In a comparison between Box-Bhenken Design (BBD) and Central Composite Design (CCD), the Box-Bhenken Design trial is more effective since it uses less run/experimental units (Purwanti & Ferihan, 2021). Although the number of runs is less, Box-Bhenken is able to predict the optimum value both linear and quadratic well (Sopyan *et al.,* 2022; Perincek & Colak, 2012).

The best formula is found using the Design Expert Factorial approach, which also identifies how the independent variable interacts with other variables. Using mathematical calculations in the Design-Expert programme, the optimal formula is predicted based on the interactions between each variable. Following the previous prediction, the experiment was next conducted in the laboratory (wet lab). The outcomes of the dependent variable will be impacted by this independent variable, same like in software Design Experts. The dependent variable's value is utilised to calculate the best formula, and the software's anticipated results are contrasted with the actual trial outcomes. The method was successfully used to evaluate the effect of formulation variables and improve the optimized formulation, thereby reducing the number of trials, time, and costs of formulation development.

Sopyan *et al.,* (2022) concluded that Design Expert software is useful for formulation since it makes it simpler for the formulator to choose the best formula. Software can be used to assess the impact of formulation parameters for each preparation using a variety of approaches. As a result, there are benefits and drawbacks to the experiment's design. The benefit of DOE with Design Expert is that it takes less time and fewer trials to develop formulas. DOE with Design Expert has a limitation that leads to a value prediction error of less than 4%: the reliance on software as an optimisation tool.

MATERIALS AND METHODS

CHAPTER 3
MATERIALS AND METHODS

Various engineering properties required to design and development of jackfruit seed peeler are described in this chapter. Also the methodology of fabrication and evaluation procedures of jackfruit seed peeler and optimization of process parameters for the development of seed peeler are also included in this chapter.

3.1 Procurement of raw materials

Matured jackfruits were procured from the Instructional Farm at KCAET, Tavanur. Primary processing operations were performed using the jackfruit peeler, corer cum cutter developed by AICRP on PHET, Tavanur centre. The jackfruit seeds were extracted manually from jackfruit bulb. The seeds were properly cleaned and stored at refrigerated conditions at an optimum temperature of around 10 °C, (Merlin & Palanisamy, 2000) till the conduct of the experiment.

3.2 Engineering Properties of Jackfruit Seeds

Engineering properties are the properties which are useful and necessary in the design and operation of various equipments employed in the field of agricultural processing and also for design and development of farm machines. Engineering properties such as length, sphericity, roundness, density, coefficient of friction, moisture content, water activity etc. of jackfruit seeds were evaluated based on the standard procedures described below.

3.2.1 Dimensions of Jackfruit Seed

Length, width and thickness of the jackfruit seeds were measured using a digital vernier calliper. It is expressed in mm.

3.2.2 Moisture Content

Moisture content of jackfruit seed was determined using of infrared moisture meter. An infrared moisture meter is an instrument that substitutes the loss on drying method used for many official analytical methods for moisture determination.

The equipment determines moisture of a sample by heating and drying it with infrared irradiation and displays the moisture content measured from changes in mass due to evaporation. After the calibration of the moisture meter, place the finely chopped sample in the sample holder. Activate the measurement function on the moisture meter by pressing the button. Wait for the instrument to acquire a stable reading, which may take a few seconds. Record the moisture content reading displayed on the instrument. The process was repeated multiple times and the average value was taken.

Plate 3.1. Infrared moisture meter

3.2.3 Geometric Mean Diameter

Geometric mean diameter is used to determine the morphology of the jackfruit seed. Digital vernier callipers were used to measure the length, breadth, and thickness of the seeds in order to calculate the geometric mean diameter of the jackfruit. Using information about spatial dimensions and the following formula, developed by Kachru *et al.,* (1994), the geometric mean diameter (Dg) of the samples were measured.

$$Dg = (L \times B \times T)^{1/3} \qquad ...3.\ 1.$$

where,

L = Length, mm

B = Breadth, mm

T = Thickness, mm

3.2.4 Sphericity

Sphericity may be defined as the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle. This parameter shows the shape character of the particle relative to the sphere having same volume. Sphericity is employed to describe the shape of the jackfruit seed. As a result, the sphericity (Sp) was calculated in accordance with the method provided by Sahay and Singh (1994).

$$Sp = \frac{Dg}{L} \qquad ...3.2.$$

where, Dg = Geometric mean diameter,

L = Length, mm.

3.2.5 Roundness

It is a measure of the sharpness of the corners in the solid. Several methods have been proposed for estimating roundness. An overhead projector was used in the determination of roundness.

$$Roundness = \frac{Ap}{Ac} \quad \text{...3.3.}$$

where, Ap = Largest projected area of object in natural rest position,

Ac = Area of smallest circumscribing circle.

Plate 3.2. Overhead Projector

3.2.6 Bulk Density

The bulk density of jackfruit seed was assessed using an empty carton box of 300×185×120 mm having an internal volume of 6660 cm^3. The box was filled with jackfruit seeds and the bulk weight was measured. The bulk density was calculated using the formula given below. The experiment was replicated 10 times and the mean value was recorded. The formula provided by Kacharu *et al.,* (1994) was used to calculate it.

$$Bulk\ density = \frac{Mass\ of\ sample}{Volume} \quad \text{...3.4.}$$

3.2.7 True Density

The true density of the jackfruit seed was determined by the water displacement technique (Dutta *et al.,* 1988). Ten numbers of randomly selected jackfruit seeds were weighed individually and immersed in water in a measuring cylinder and ensured that the jackfruit seed was completely submerged during immersion in water. The volume of water displaced by each seed was recorded and the true density was calculated using the following equation:

$$True\ density = \frac{Unit\ mass\ of\ jackfruit\ seed}{Displaced\ volume} \quad ...3.5.$$

3.2.8 Water Activity

Water activity of the feed mix was determined by using Aqua lab water activity meter (M/s Aqua lab, Decagon device Inc., Pullman (Wa), USA) which is shown in Plate 3.4a. The sample was put into the disposable cups of water activity meter and turned the sample drawer knob into OPEN or LOAD position. Then the drawer was pulled to open and the cup along with sample was placed in the drawer. While placing samples in the drawer, care should be taken that top Hp of the cup must free from sample residue. Then closed the drawer and turned the knob to READ position. The water activity of samples was displayed on the LCD display and the values were recorded.

Plate 3.3 Water Activity Meter

3.2.9 Coefficient of Friction

Coefficient of friction (*f*) is the ratio of force of friction (F) and the force normal to the surface of contact (W).

$$f = \frac{F}{W} \qquad ...3.6.$$

The coefficient of friction may also be given as the tangent of the angle of the inclined surface upon which the friction force tangential to the surface and the component of the weight normal to the surfaces are acting.

Plate 3.4 Apparatus for the measurement of Coefficient of Friction

Coefficient of friction was determined using the apparatus given in the Plate.3.4. The apparatus consists of a frictionless pulley fitted on a frame or bottomless hollow cylinder, a loading pan and test surface. The cocoa was tied at one end using a thread and placed on the test surface and weight was added on loading pan until the cocoa pod began to slide. The weight of the pod and the weight added on loading pan represents the normal force (N) and lateral force (F), respectively (Sahay and Singh, 2010).

3.3 Development of jackfruit seed peeler

Based on the preliminary studies, jackfruit seed peeler was developed and the performance was evaluated for the same. It removes Jackfruit seed coat by the principle of impact and abrasion forces between the seed and the inner perforated cylinder. The machine is operated using a 1 hp motor through belt and pulley system. The major components of the machine are listed below.

1) Frame assembly

2) Outer cylinder

3) Perforated inner cylinder

4) Base plate with ring and bearing

5) Rotating disc

6) Connecting shaft

7) Hollow shaft with bearings on both ends

8) Belt and pulley

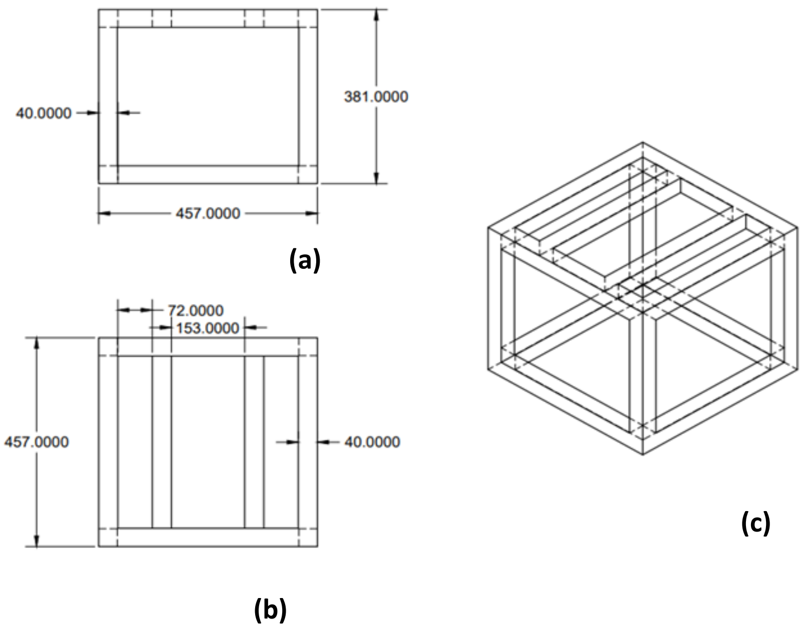
9) Motor and VFD

10) Water outlet

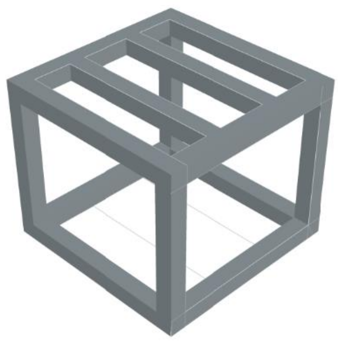
3.3.1 Frame assembly

It is a supporting structure in which motor, cylinder and all the other parts are attached. Frame is made of mild steel angles of thickness 6mm width 39mm and is coated with grey coloured anti-corrosive epoxy coating. The frame is also supported with two additional parallel angles at the top for supporting outer cylinder. Frame was constructed using two square angles at top and bottom supported by 4 vertical angles at all four corners. The overall dimensions of the frame are 457 × 457 × 381 mm. Two parallel supports are placed at 72 mm each from opposite edges and are 153mm apart from each.

Plate 3.5 Frame assembly



(A)



(B)

Fig. 3.1A) Isometric projection of frame asssembly a) Side view b) Top view c) Isometric view

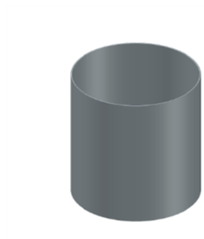
B) 3D drawing of frame assembly

(All dimensions are in mm)

3.3.2 Outer cylinder

Outer cylinder is a circular cylinder of thickness 1.5 mm and is made of stainless steel. The circular cylinder supports inner perforated cylinder and is attached to the frame. It has 400 mm height, 316 mm outer diameter and 313 mm inner diameter. The cylinder was welded to the base plate.

Plate 3.6 Outer cylinder



(A)

(B)

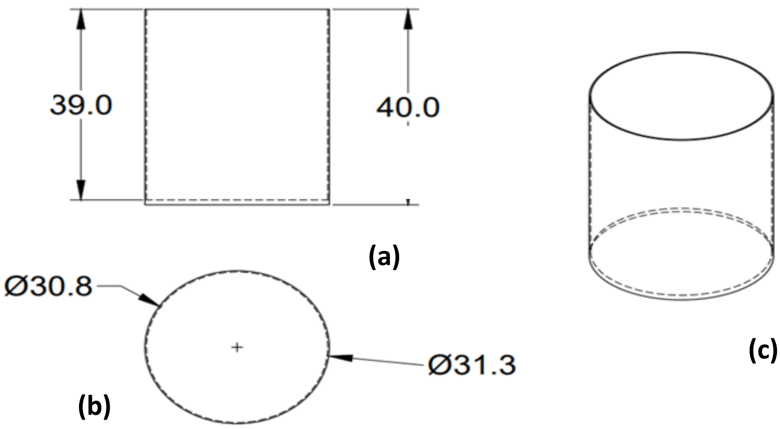


Fig. 3.2 A) 3D drawing of outer cylinder

B) Isometric projection of outer cylinder a) Side view b) Top view c) Isometric view

(All dimensions are in mm)

3.3.3 Perforated inner cylinder

Inner cylinder is a circular cylinder was made of stainless steel of thickness, height, Inner and diameter 1 mm, 315 mm, 311 mm and 313 mm, respectively. Perforations of 2mm were provided at an interval of 2mm both horizontally and diagonally. The cylinder is detachable from outer cylinder. Four hooks or clamps were provided on the top end of the perforated cylinder to prevent it from sliding down while operating and to help in its removal after operation.

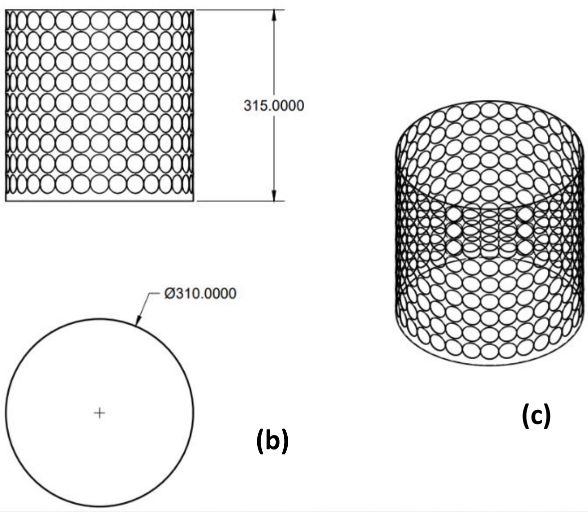


Fig. 3.3 1) Isometric projections of Perforated inner cylinder a) Front view b) Top view c) Isometric view

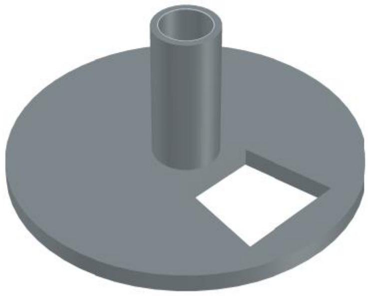
(All dimensions are in mm)

Plate 3.7 Bending of perforated sheet

3.3.4 Base plate with ring and bearing

Base plate was welded on supporting angles and holds outer cylinder, ring and bearing at top and hollow cylinder with bearing at bottom. It is made using stainless steel of thickness 10mm and diameter 313 mm. A trapezoidal slit with 7.8 mm, 10mm parallel sides and 10 mm side lengths is cut out to aid the water outlet.

Plate 3.8 Base plate with ring and bearing and trapezoidal slit



1) 2)

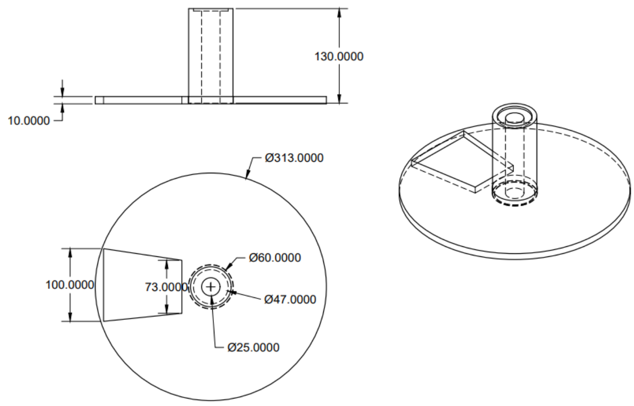


Fig. 3.4 1) 3D drawing

2) Isometric projections of base plate a) Front view c) Isometric view

3.3.5 Rotating disc with perforated sheet

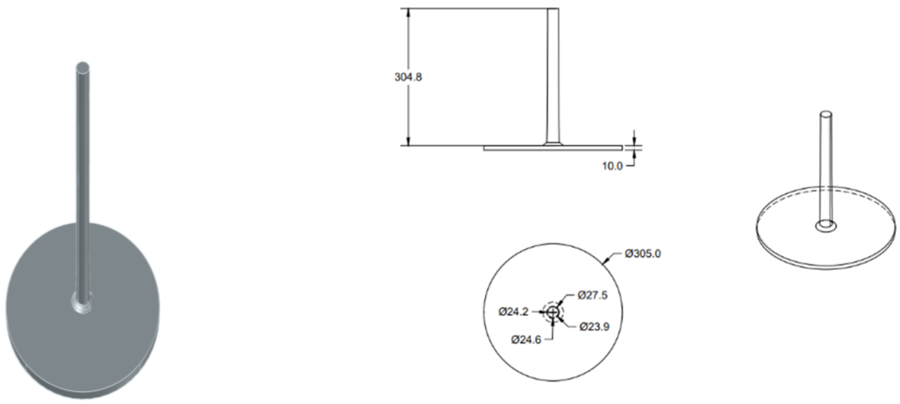
Rotating disc of 305mm diameter and 10mm thickness was welded to solid shaft of length 304.8mm. It is made up of stainless steel. It is rotated by the shaft which is connected to the motor through belt and pulley. Due to this rotation, the jackfruit seeds are subjected to impact and abrasive forces which results in seed coat removal. A perforated sheet of 1.18 mm thickness and the same diameter as that of the disc is welded on it. The perforations are of 10.1mm diameter. This also helps in the abrasion. It also has a rubber wiper attached to the bottom part to wipe out the waste and water while cleaning. The rotating disc was welded with a 2mm strip of stainless steel on the top and passing through the diameter of the disc to provide a minimum agitation.

Plate 3.9 Rotating disc with perforated sheet and agitating strip

3.3.6 Connecting Shaft

Connecting shaft of stainless steel 304.8 mm length with tapering was welded on the rotating disc. The end of the shaft with 27.8 mm diameter was welded on the disc. Diameter of the other end is 24.2mm. It was connected to the motor through belt and pulley. It rotates the rotating disc.

Plate 3.10 Connecting shaft welded on the rotating disc



1) 2)

Fig. 3.5 1) 3D drawing

2) Isometric projection a) Front view b) Top view c) Isometric view

(All dimensions are in mm)

3.3.7 Hollow shaft with bearings on both end

It consists of a mild steel hollow shaft of inner diameter 47mm and outer diameter 60mm. It is 127mm long. Roller bearings of 25mm inner diameter and 47 mm outer diameter were provided on both ends of the hollow shaft to support the solid shaft. The connecting shaft is suspended in the hollow shaft and the bearings reduce friction and allow for smoother rotation.

Plate 3.11 Boring of shaft

3.3.8 Belt and Pulley

Two pulleys of 152.4 mm and 76.2 mm diameters were placed on the connecting shaft and the motor, respectively. The pulleys transmit motion from motor to the shaft. A B38 belt is used to track the relative movement between two the pulleys.

Plate 3.12 Belt and Pulley arrangement

3.3.9 Motor and VFD

A 0.75 kW motor was used to rotate the connected shaft. Variable Frequency Drive (VFD) which requires 1 hp input power was attached to the motor. It is a type of motor controller that drives an electric motor by varying the frequency and voltage of power supply.

Plate 3.13 Variable Frequency Drive (VFD)

3.3.10 Water Outlet

A trapezoidal opening with 7.8 mm, 10mm parallel sides and 10 mm side lengths was cut out to aid the water outlet on the base plate. All the measurements of the outlet are given below. It is provided to remove the waste materials during cleaning with water.

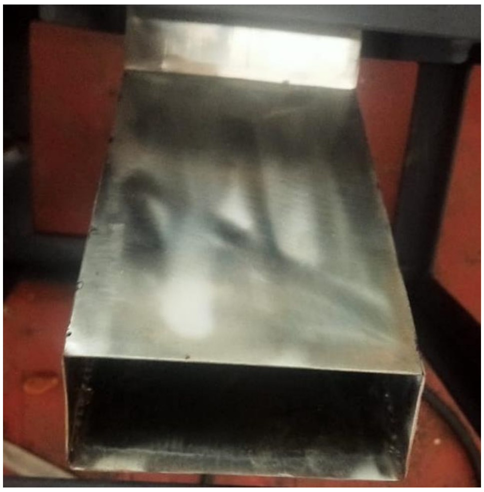


Plate 3.14 Water Outlet

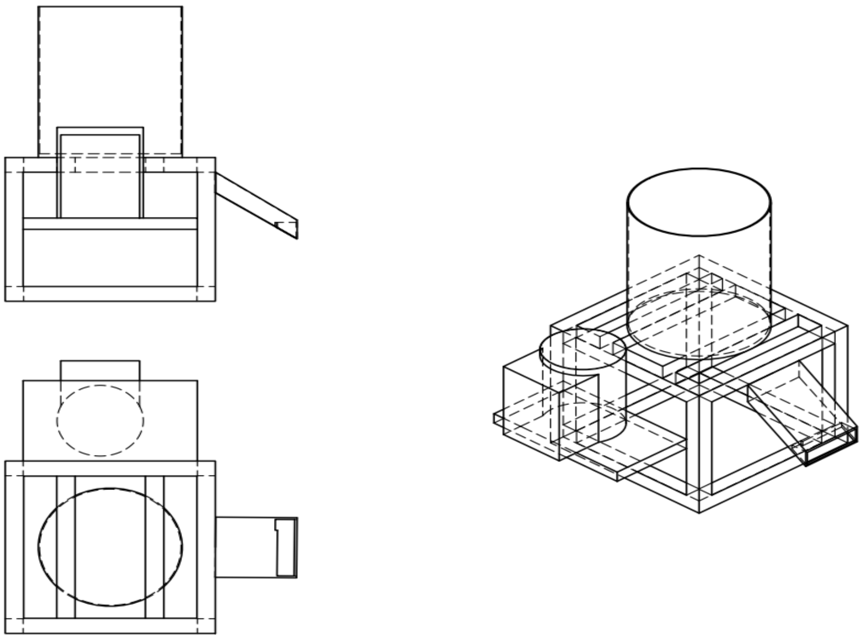


Fig. 3.6 Isometric projection of jackfruit seed peeler a) Front view b) Top view c) Isometric view

Table 3.1 Specifications of newly developed jackfruit seed peeler

Sl. No.	Items	Values
A	**Frame**	
i)	Outer cylinder outer diameter	316 mm
ii)	Outer cylinder height	400 mm
iii)	Overall dimensions	457 × 457 × 381 mm
B	**Peeler Assembly**	
i)	Inner perforated cylinder height	315 mm
ii)	Inner perforated cylinder outer diameter	313 mm
iii)	Rotating disc diameter	305 mm
iv)	Perforations on the sheet attached to the disc.	10.1 mm
C	**Power transmission unit**	
i)	Motor	1 hp
ii)	VFD input power	1 hp
iii)	Connecting shaft length	304.8 mm
v)	Hollow shaft length	127 mm
vi)	Hollow shaft outer diameter	60 mm
vii)	Number of belts	1
viii)	Number of pulleys	2

3.4 Operational procedure for jackfruit seed peeler

Jackfruit seeds were cleaned and dried in the sun for 1 to 2 hours before peeling. After removing the inner perforated cylinder, it was cleaned thoroughly along with the rotating disc with the perforated sheet. The jackfruit seeds were fed into the cylinder at desired height and the lid was closed. The machine was operated by a motor and VFD through a belt and pulley system. The rotational speed was controlled using the VFD. The operations were done at various speeds, time and bed thickness. Seed coat was removed due to the impact and abrasion forces of the seed on the perforated inner cylinder and the perforated sheet welded on the rotating disc. The peeled jackfruit seed was collected through the door provided on the outer cylinder after detaching the inner perforated cylinder from the jackfruit seed peeler. The rubber wiper provided below the rotating disc also helps in the cleaning process with or without water

3.5 Performance evaluation of jackfruit seed peeler

3.5.1 Experimental design

RSM designs allow us to estimate interaction and even quadratic effects, and therefore give us an idea of the (local) shape of the response surface under investigation. Box-Behnken designs and central composite designs are efficient designs for fitting second order polynomials to response surfaces, because they use relatively small number of observations to estimate the parameters. The design layout after specifying the independent and dependent parameters were obtained using the software. The independent and dependent variables considered in the study are given below.

Table 3.2 Independent and dependant variables

Independent variables	Levels	Dependent variables	Units
Time (minute) i)0.5 ii)1.0 iii)1.5	3	Peeling efficiency Material loss Percentage seed damage	% % %
Speed (Hz) i)30 ii)40 iii)50	3		

3.5.1.1 Dependent Parameters

Dependant parameters are calculated to optimize the independent parameters to get the maximal working condition. Peeling efficiency, material loss and seed damage were taken as dependent parameters.

3.5.1.1.1 Peeling efficiency

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

Peeling efficiency (%) $= \frac{Y-Z}{Y} X100$ *....3.7.*

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

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

3.5.1.1.2 Material loss

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

Material loss $= \frac{W}{W+X} X100$ *....3.8.*

Where, W = Weight of seed obtained from the peeled produce (g)

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

3.5.1.1.3 Percentage seed damage

The numbers of damaged seeds during peeling operation were observed. The seed damage, expressed in percentage was calculated by using the formula given below.

Percentage seed damage $= \frac{Number\ of\ damaged\ seeds}{Total\ number\ of\ seeds} X100$ *....3.9.*

3.5.2 Optimisation of process parameters of jackfruit seed peeler

The process parameters were optimized with the RSM software. RSM designs allow us to estimate interaction and even quadratic effects, and therefore give us an idea of the (local) shape of the response surface under investigation. Box-Behnken designs and central composite designs are efficient designs for fitting second order polynomials to response surfaces, because they use relatively small number of observations to estimate the parameters. The purpose of RSM is optimization and the location of optimum is unknown prior to running the experiment, it makes sense to use a design that provides equal precision of estimation in all directions. For such purposes, Central Composite Design (CCD) - spherical or face centered and Box – Behnken design are the commonly used experimental design models for three level three factor experiments (Joseph et al., 2008). Upon considering time and speed as factor 1, and factor 2 respectively, 13 different combinations were obtained using Central Composite Design method.

3.5.3 Comparison of developed jackfruit seed peeler machine with manual peeling

The efficiency of the developed machine was compared with manual method. Manual peeling was carried out by employing one labour and the results were compared with mechanical operation to assess the throughput and capacity. The throughput was calculated by using formula (Jimoh and Olukunle, 2012)

$$\text{(Processing time, h)} = \frac{\text{(Total weight of peeled jackfruit seed, kg)}}{\text{Throughput (kg/h)}} \qquad \ldots 3.10.$$

The total processing time for mechanical operation of peeling for each sample was recorded using stop watch. Similarly, time of manual operation was calculated by considering the peeling time. The processing time per seed was calculated by following formula

$$\textit{Processing time (min/jackfruit seed)} = \frac{\textit{Total time of processing}}{\textit{Number of jackfruit seeds}} \quad \ldots 3.11.$$

3.5.4 Cost economics

Based on the material cost and cost of fabrication, the total cost of developed jackfruit seed peeler machine was worked out. The operation cost of mechanical and manual operation was worked out, by including the fixed and variable costs. The benefit-cost ratio was determined by considering cost of raw materials needed for the machine preparation, jackfruit seeds rate and selling price of the processed machine.

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

This chapter deals with the results obtained from various experiments conducted to determine the engineering properties of jackfruit seed, development and performance evaluation of jackfruit seed peeler.

4.1 Engineering properties of jackfruit seed

The engineering properties of jackfruit seed such as length, width, geometrical mean diameter, sphericity, roundness, coefficient of friction, water activity, moisture content were evaluated as per the standard procedures.

4.1.1 Size

Size viz. length, width, and thickness of jackfruit seed are important for fixing the perforated cylinder dimension of the developed jackfruit seed peeler. The average length, width and thickness of jackfruit seed were found to be 35.82 mm, 18.07 mm and 15.85 mm, respectively. The present result of seed length, width and thickness were found to be closer with the findings of Divekar and Barge (2017).

The average geometric mean diameter was calculated by using length, width and thickness of the seed and was found to be 21.67. The sphericity and roundness were found out by using overhead projector. The sphericity of jackfruit seed was in between 0.385 and 0.472 and the average roundness was determined as 0.456.

4.1.2 Bulk density, true density and porosity

The bulk density, true density and porosity of jackfruit seeds were determined using the standard procedures mentioned in sections 3.17 and 3.18. The average bulk density, true density and porosity was found as 0.531 g/cm^3, 1.09 g/cm^3 and 56.55, respectively.

4.1.3 Moisture content and Water activity

Moisture content of jackfruit seed was determined by infrared moisture meter. The average moisture content of the jackfruit seed was found as 47.36 %. Water activity is the amount of available water for chemical reaction. In this experiment the water activity was detected by water activity meter and the value obtained was 0.985.

Table 4.1 Engineering Properties

SL NO.	PROPERTY	RANGE	AVERAGE OBSERVED VALUE
1	Length, mm	32.69-38.82	35.82
2	Width, mm	14.65-20.97	18.07
3	Thickness, mm	13.81-18.83	15.85
4	Mass, gm	5.24-8.38	7.236
5	True density, g/cm^3	0.888- 1.50	1.09
6	Bulk density, g/cm^3	0.460-0.567	0.531
7	Porosity	46.33-69.33	56.55
8	Moisture content, %	47.36-59.2	55.186
9	Geometric mean diameter	19.80-23.45	21.67
10	Sphericity	0.385-0.472	0.436
11	Roundness	0.298-0.665	0.456
12	Coefficient of friction	0.5477	0.5477
13	Water activity	0.985-0.986	0.985

4.2 Performance evaluation of jackfruit seed peeler

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

4.2.1 Peeling operation of developed machine

The performance evaluation of the peeler of developed machine was carried out with different speed of VFD and time of operation.

4.2.2 Design of experiments

RSM designs allow us to estimate interaction and even quadratic effects, and therefore give us an idea of the (local) shape of the response surface under investigation. Box-Behnken designs and central composite designs are efficient designs for fitting second order polynomials to response surfaces, because they use relatively small number of observations to estimate the parameters.

The design layout after specifying the independent and dependent parameters were obtained using the software. About 13 combinations were obtained and its results are given in the table below.

4.2.3 Effects of time and speed on various dependent parameters

The effects of speed and time on process parameters such as peeling efficiency, material loss, and percentage seed damage were statistically analyzed using Central Composite method and 13 combinations of experiments were conducted. The data corresponding to the various combinations were entered. The results revealed that two factors had a significant effect on the evaluated parameters. It is shown in Table 4.2.

Table 4.2 Design layout

Std	Run	Factor 1 A:speed Hz	Factor 2 B:time min	Response 1 peeling efficiency %	Response 2 material loss %	Response 3 Seed damage %
3	1	30	1	80.32	0.048	2.397
2	2	30	1.5	87.5	0.71	3.26
11	3	30	0.5	37.7	0.139	0.341
5	4	40	1	98.8	0.699	2.405
13	5	40	1	98.8	0.699	2.405
12	6	40	1	98.8	0.699	2.405
9	7	40	0.5	60.6	0.208	0.696
6	8	40	1	98.8	0.699	2.405
4	9	40	1	98.8	0.699	2.405
10	10	40	1.5	99.28	1.19	5.802
8	11	50	0.5	75	0.489	2.397
7	12	50	1	99.81	1.48	4.42
1	13	50	1.5	96.558	3.6	12.84

4.2.4. Effect of process parameters on peeling efficiency

The effect of process parameters on peeling efficiency is tabulated in Table 4.2. From the table, it is observed that the peeling efficiency of the developed machine increased with increase in time and speed. Result shows that both speed and time have a significant effect on peeling efficiency. The peeling efficiency of the machine was in the range of 37.7-99.81%. The maximum peeling efficiency of 99.81% was obtained at a frequency of 50 Hz and time 1 minute.

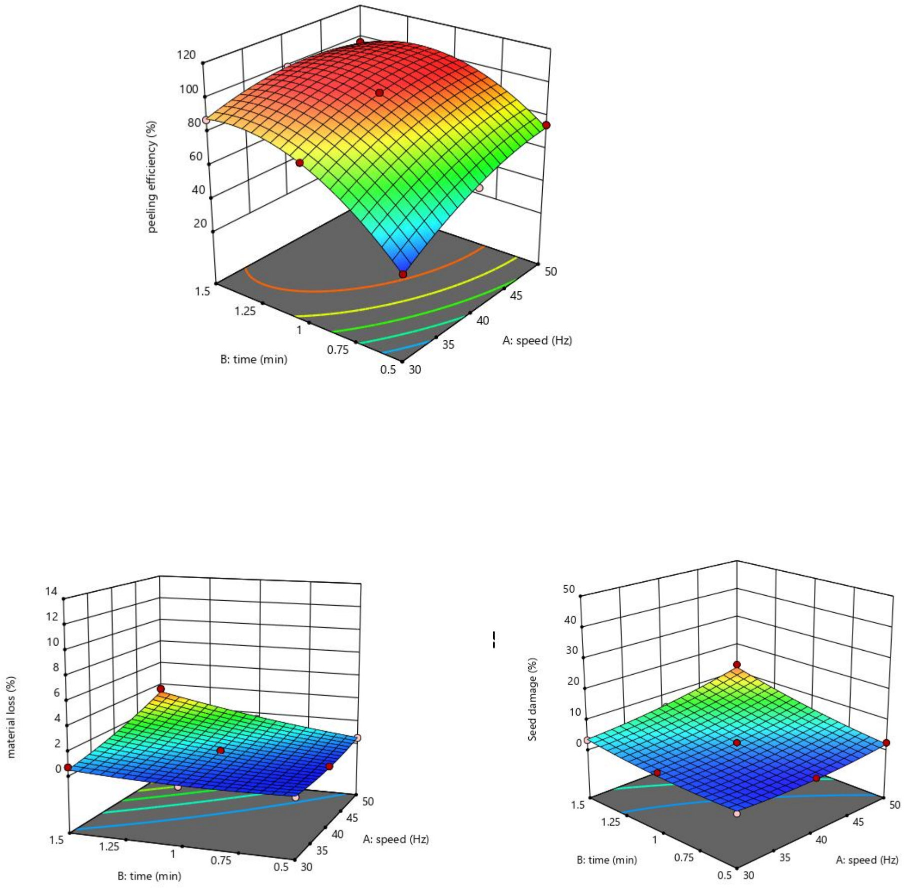
4.2.5. Effect of process parameters on material loss

It is observed that material loss increased with increase in speed and time. The result showed that time and speed had a significant effect on material loss. The maximum material loss of 3.6% was resulted at 50 Hz and 1.5-minute operation (Fig.4.1 b).

4.2.6. Effect of process parameters on percentage seed damage

The effect of process parameters on seed damage is tabulated in Table 4.2. From the table, it is observed that the percentage seed damage of the developed machine increased with increase in time and speed. The seed damage of the machine was in the range of 0.341-12.84%. The maximum seed damage was obtained at a frequency of 50 Hz and time 1.5 minute, whereas the minimum seed damage was observed at a frequency of 30 Hz and time 0.5 minute.

(a)



(b) **(c)**

Fig.4.1 Effects of process parameters on dependent parameters (a) Variation of peeling efficiency with time and speed (b) Variation of material loss with time and speed. (c) Variation of seed damage with time and speed.

4.2.7 Optimization of process parameters

With the help of the RSM software the optimized results were obtained. The optimum speed and time of the developed machine was attained at 39.999Hz (2398 rpm) [Fig.4.2] and 0.984 minutes, [Fig.4.2] respectively. The peeling efficiency, seed material loss and percentage seed damage at optimized conditions were found to be 97.7852%, 0.6095% and 2.2448%, respectively. The optimum capacity was of the machine was calculated as 22.5 kg/h.

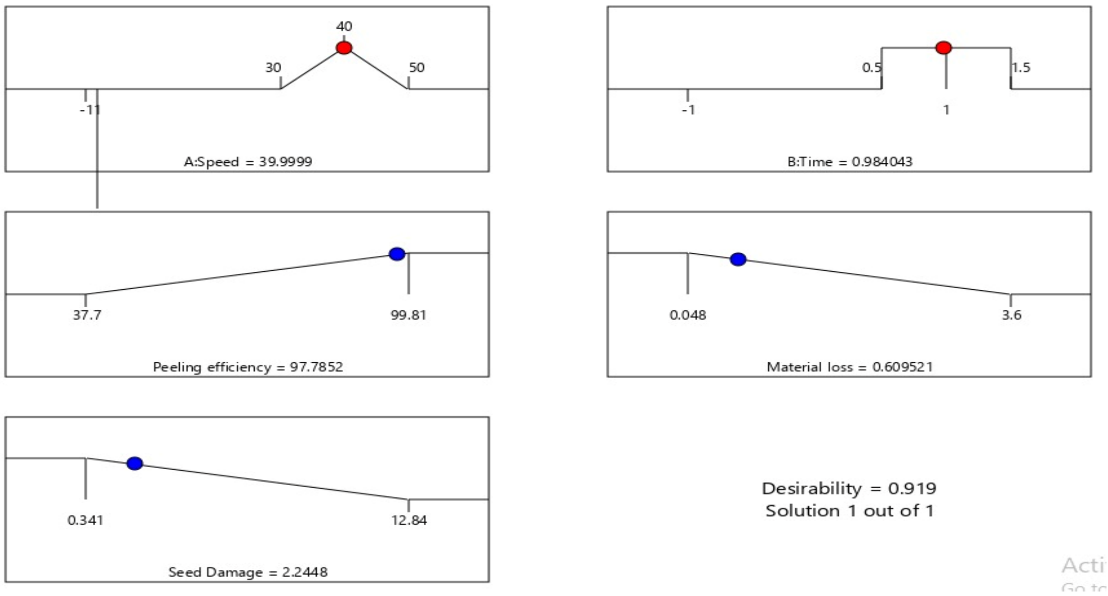


Fig.4.2. The graphical result of the optimal values of different parameters

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

The performance of the developed jackfruit seed peeler was compared with comparison study was conducted between traditional method. The average time taken for peeling of jackfruit seed using manual peeling was 0.5 min/ seed, whereas for mechanical operation the time taken was only 0.003 min/fruit, which is too lesser than manual operation. The maximum throughput of the developed machine and manual peeling were found to be 22.5 kg/h and 0.943kg/h, respectively.

4.4 Cost economics

The operational cost of the machine was estimated as Rs.44.6/ hour. The cost of the developed jackfruit seed peeler machine was found to be Rs.43250/-. The benefit-cost ratio of the developed machine was 1.84:1.00.

SUMMARY AND CONCLUSION

CHAPTER 5
SUMMARY AND CONCLUSION

Jackfruit (*Artocarpus heterophyllus L.*) belongs to the family Moraceae which is popular and important underutilized fruit. India is the highest producer of Jackfruit in the world. Bangladesh leads second in volume, followed by Thailand, Indonesia and Nepal. The total cultivated area and production in India during 2021-2022 has been 18.76 Lakh tonnes over1.87 Lakh hectares of land. In Kerala the annual production of jackfruit is 2.63 Lakh tonnes contributing to 14.01% of its share to India (APEDA, 2021-22). In Kerala, jackfruits are classified into two general types; 'Koozha Chakka' and 'Varikka Chakka'. The former has small, fibrous, soft, mushy, but very sweet carpel whereas the latter is more important commercially, with crisp carpel of high quality. The jackfruit has lost its status and now it is one of the under exploited fruits of the state. The fruit is frequently referred to as 'poor man's food', as it is cheap and plentiful during the summer season when food is scarce. The seeds can also be roasted or boiled and eaten as a nutritious snack. Jackfruit is a highly nutritious fruit, rich in vitamins, minerals, and antioxidants. It is also a good source of dietary fibre and protein, making it a healthy addition to any diet.

Currently, jackfruit is in high demand because of its accessibility, sweetness, and nutritional value. Diversified value-added products are required for consumption by all consumer age groups. Sensitive farmers, volunteers and business people might concentrate more on jackfruit value-added items. However, typical manual peeling takes a lot of time and work. The main cause of this fruit's underutilization is the tediousness in manual processing. Therefore, efficient mechanization of this procedure is urgently needed.

Jackfruit seeds are often discarded as waste, but they are actually a valuable part of the fruit that can be used in a variety of ways. Jackfruit seeds are a good source of protein, dietary fiber, essential vitamins and minerals such as iron, magnesium, and zinc. They are also low in fat and calories, making them a healthy addition to any diet. Jackfruit seeds can be roasted, boiled, or ground into flour and used in a variety of dishes. In some parts of India, they are used as a substitute for lentils or chickpeas in curries and stews. They can also be eaten as a snack after roasting or boiling. They have been used in traditional medicine to treat a variety of ailments, including diarrhea, fever, and skin diseases. They are believed to have anti-inflammatory and antioxidant properties that can help improve overall health. It contains a type of starch called "jackfruit starch" which can be used in the manufacturing of various industrial products such as adhesives, paper, and textiles. Jackfruit seeds are often discarded as waste, but they have the potential to provide a valuable source of income for farmers and entrepreneurs. In recent years, there has been growing interest in jackfruit seeds as a sustainable and nutritious food source, which has led to increased demand and higher prices in some markets.

The jackfruit seed processing is limited due to time consuming and tedious peeling process. If effective mechanization in jackfruit seed peeling is possible, more seeds could be processed in less time and hence more valuable jackfruit products may be produced overall. Second, by lowering the possibility of contamination during the peeling process, a seed peeler can raise the caliber of jackfruit products. The nutritional value and general quality of the seeds may be impacted by the introduction of dirt, germs, and other pollutants during manual peeling. By ensuring that the seeds are thoroughly cleaned and sanitized before processing, a seed peeler can help lower the risk of contamination and boost the quality of the finished product.

The invention of a seed peeler may open up new prospects for the jackfruit sector. More goods may be made from jackfruit seeds with enhanced productivity and higher quality, which might open up new markets and boost demand for jackfruit products. In addition to promote the expansion of the agricultural industry overall, this might assist farmers and companies who grow jackfruit.

As an attempt to overcome these problems, a study was conducted at KCAET, Tavanur to modify the existing machine using stainless-steel perforated sheet as inner cylinder instead of emery coating as the abrasive material with the objectives- a) To study the engineering properties of jackfruit seed, b) To modify the existing power operated seed coat remover for jackfruit seed and c) To study the performance of the modified machine in terms of peeling efficiency, seed damage, material loss etc.

Matured, ripened jackfruits harvested from the instructional farm of K.C.A.E.T, Tavanur and seeds were collected, which was used for the study. Before the fabrication of the machine, the selected physical and mechanical properties of jackfruit seeds were studied. The length, width, and thickness of jackfruit seed are important for fixing the perforated cylinder dimension of the jackfruit seed peeler machine. Weight of seed was important in determining the factor of safety distribution in designed cylinder and capacity of the motor in order to withstand against maximum load during the peeling operations. Geometric mean diameter, roundness, sphericity, water activity and moisture content were also evaluated.

Based on the preliminary studies, jackfruit seed peeler machine was conceptualized, designed and fabricated. The major components of the machine are inner perforated cylinder, outer cylinder with rotating disc which doing peeling operation, power transmission unit and frame assembly.

Working principle of this machine is abrasion and impact force. Jackfruit seeds were cleaned and dried in the sun for 1 to 2 hours before peeling. After removing the inner perforated cylinder, it was cleaned thoroughly along with the rotating disc with the perforated sheet. The jackfruit seeds were fed into the cylinder at desired height and the lid was closed. The machine was operated by a motor and VFD through a belt and pulley system. The rotational speed was controlled using the VFD. The operations were done at various speeds, time and bed thickness. Seed coat was removed due to the impact and abrasion forces of the seed on the perforated inner cylinder and the perforated sheet welded on the rotating disc. The peeled jackfruit seed was collected through the door provided on the outer cylinder after detaching the inner perforated cylinder from the jackfruit seed peeler. The rubber wiper provided below the rotating disc also helps in the cleaning process with or without water

Performance evaluation of the machine was conducted in the laboratory to optimize the speed of peeling and minimize the material loss and percentage seed damage. The peeling action was studied at 30 Hz, 40 Hz and 50 Hz at different times such as 0.5 min, 1 min and 1.5 min. The peeling efficiency was highest (99.81%) at a speed of 50 Hz whereas, lowest (37.7%) at a speed 30 Hz. The highest material loss (3.6%) was observed at 50 Hz whereas, lowest (0.048%) was at 30 Hz. Speed of 39.9999 Hz was found to be optimal for peeling operation, in respect of 0.984043 minutes time for higher peeling efficiency and lowest material loss. The maximum peeling efficiency found to be 97.7852 %, material loss and seed damage were found as 0.6095 % and 2.2448 % respectively. Optimized capacity of the machine is 22.5kg/h.

Comparative study of manual method of jackfruit seed peeling with the developed jackfruit seed peeler machine was carried out by considering throughput and total time. The maximum throughput of machine was 22.5kg/h whereas in manual operation 0.943kg/h which is lesser than the mechanical operation. The average taken time for peeling was maximum (0.5min/seed) in manual operation and in case of mechanical operation (0.033 min/seed), which is higher than manual operation. This indicated that the developed machine aids in faster peeling of jackfruit seeds with least drudgery besides more efficient and also could be used in small and medium scale industry.

The cost of the developed machine was Rs. 43250/-. The operational cost of machine was Rs.44.635/h. The benefit-cost ratio of machine was calculated as 1.84 :1.00.

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CHAPTER 6
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APPENDIX

CHAPTER 7
APPENDIX

Comparison of modified jackfruit seed coat remover machine with manual operation.

A. Manual Operation

A.1 Capacity calculation (kg/h)

Total weight of jackfruit seed = 78.6 g

Total time of operation= 5 minute

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

= (0.0786×60)/5

=0.943 kg/h

Time required per seed(min/seed)= (5)/10

=0.5 min/seed

A.2. Cost analysis of manual operation

A.2.1Assumption

1. Number of workers required = 1

2. Working hours per day = 8h

3. Wages of worker (1person) per day of 8hours = Rs. 300

A.2.2 Cost of manual operation per hour

(i) Wages of worker per hour (A) = 300÷ 8 = Rs. 37.5/-

Total cost of operation per hour = Rs. 37.5 /-

A.3 Assumptions

1. Cost of jackfruit seed per kilogram = Rs. 3 /-

2. Manual working hours per day = 8 h

3. Manual working days per year = 120 days

4. Selling price of processed seeds per kilogram = Rs. 10/-

A.3.1 Actual performance

1. Cost of manual operation per hour = Rs.37.5 /-

2. Actual capacity of worker = 0.943 kg/h

B. Mechanical operation

B.1. Capacity calculation (kg/h)

Total weight of jackfruit seed = 1.5 kg

Total time of operation = 4 min = 0.066h

(Total weight of jackfruit) Throughput (kg/h) =22.5kg/h

B.2. Time required per fruit (min/fruit)= 1/292 = 0.033min/seed

B.3 Number of jackfruit processed per hour= 292×60=17520/-

B.4 Cost analysis of mechanical operation

B.4.1 Fabrication cost of the machine including the cost of material=43250/-

B.4.2 Assumptions

1) Expected life years (L) = 10 years

2) Salvage value @ 10 % of machine cost (S) = Rs. 4325/-

3) Rate of interest per year (i) = 12%

4) Number of workers required = 1

5) Wages of worker (1person) per day of 8 hours = Rs. 300 /-

6) Working days per year = 120 days

7) Working hours per day = 8 h

8) Annual use (H) (expected operational hours) = 960 h

9) Repair and maintenance cost = 5% of machine cost

10) Insurance and shelter = 1.5% of machine cost

11) Energy cost per kWh = Rs. 6.50 /-

B.4.3 Fixed cost per hour

(i) Depreciation cost (D) per hour=Rs.1.49/-

(ii) Interest (E)/hour= Rs. 2.97/-

(iii) Insurance, shelter etc., (F)/hour= Rs.0.675/-

Total fixed cost per hour=Rs 5.135/-

B.4.4 Variable cost per hour

(i) Wages of worker (G)/hour = 300÷ 8 = Rs. 37.5 /-

(ii) Repair and maintenance cost (H)/hour= Rs. 2.25/-

Total variable cost= Rs 39.5/-

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

= Rs.44.635/-

B.5 Benefit-cost-ratio

Cost of modified jackfruit seed peeler= Rs. 43250/-

Selling price of modified jackfruit seed peeler=Rs 80000/-

Benefit cost ratio= 1.84:1.00

ABSTRACT

MODIFICATION AND EVALUATION OF JACKFRUIT SEED PEELER

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ABSTRACT

Submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,

TAVANUR, MALAPPURAM-679 573

KERALA, INDIA

2023

ABSTRACT

A study was conducted at KCAET, Tavanur to develop jackfruit seed peeler with the objectives - a) To study the engineering properties of jackfruit seed, b) To modify the existing power operated seed coat remover for jackfruit seed and c) To study the performance of the modified machine in terms of peeling efficiency, seed damage, material loss etc. Based on the preliminary studies, jackfruit seed peeler machine was conceptualized, designed and fabricated. The major components of the machine are inner perforated cylinder, outer cylinder with rotating disc which doing peeling operation, power transmission unit and frame assembly. Working principle of this machine is abrasion and impact force. Jackfruit seeds were cleaned and dried in the sun for 1 to 2 hours before peeling. After removing the inner perforated cylinder, it was cleaned thoroughly along with the rotating disc with the perforated sheet. The jackfruit seeds were fed into the cylinder at desired height and the lid was closed. The machine was operated by a motor and VFD through a belt and pulley system. The rotational speed was controlled using the VFD. The operations were done at various speeds, time and bed thicknes. Seed coat was removed due to the impact and abrasion forces of the seed on the perforated inner cylinder and the perforated sheet welded on the rotating disc. The peeled jackfruit seed was collected through the door provided on the outer cylinder after detaching the inner perforated cylinder from the jackfruit seed peeler. The rubber wiper provided below the rotating disc also helps in the cleaning process with or without water. The performance evaluation of the machine was done at three different rotational speeds at frequencies of 30 Hz, 40 Hz and 50 Hz and three different times (0.5 minutes, 1 minute, 1.5 minutes) using Design Expert version 12. Using Central Composite Design method of Response Surface Methodology (RSM) optimization is done. The peeling efficiency, material loss and seed damage of optimum design was found as 97.7852%, 0.6095% and 2.2448% respectively at an optimized speed of 40 Hz and time 1 minute. The cost of the developed machine was Rs. 43250/-. The operational cost of machine was Rs.44.63/h. The benefit-cost ratio of machine was calculated as 1.84.:1.00.