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REVIEW PAPER

New Insights Into Post-harvest Technology and Value Addition of Jackfruit: A Review

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ABSTRACT

Jackfruit *(Artocarpus species)* is a horticultural crop, which is consumed as fruit and vegetable as well in both forms, i.e. mature and immature. In both, the forms jackfruit is having various uses, which are providing food, fuel, fodder, timber as well as various medicinal and industrial products. This paper discusses the recent advanced post harvest technology used for the processing of jackfruit for the preparation of different value added products and also types of machinery, required for postharvest operations such as peeling, cutting, coring, bulb removal, and seed processing.

Keywords: Jackfruit, Value addition, Post Harvest Technology

In India Jackfruit *(Artocarpus species)* which belongs to the family *Moraceae* is an evergreen tree. Jackfruit, also known as "Kathal" or "Phanas" produced 14.36 lakh tonnes annually in India. Commercial jackfruit cultivation is practised in a number of other nations, including Bangladesh, China, Thailand, Malaysia, Indonesia, Australia, Florida, and others. It occupies around 3.0 lakh acres of land worldwide and produces 3.6 million tonnes of edible bulbs (Wu *et al.* 2013). Jackfruit trees can be planted in poor soils and land which is having little or no agricultural and commercial value (Yutong Zhang *et al.* 2021). The labor cost and other cost required for jackfruit are very less due to it has become the fastest growing fruit tree in tropical and subtropical regions which increase its production at the rate of 15% each year (Swami *et al.* 2012; Zhang *et al.* 2018).

Jackfruit is the largest edible fruit in the world and has main components like green to yellow-brown exterior rind, yellowish edible bulbs (15-20 %), oval shape seed (8-15%), and white latex as shown in Fig. 1. The weight of single fruit is from 2 kg to 36 kg and has a maximum length of 90 cm. The seed is also edible but they are hard to digest by human digestive tracts. In Maharashtra and South India, jackfruit is classified into two general types: type 1 cultivar of Jackfruit has a firm bulb called *Kapa* and is more important commercially. It possesses crispy carpels or flakes of high quality. On the other hand,

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the type 2 cultivar of jackfruit has a soft bulb, called *Barka* whose bulbs are soft and very sweet.

The ripe jackfruit bulb has unique flavour and sweat in taste and also the seed of the jackfruit is also widely consumed as a dessert or an ingredient in many Asian culinary preparations. The cooked and salted jackfruit seed also has a good taste and the flour of the seed can also be useful for baking which is fairly rich in starch (Singh *et al.* 1991). The tender jackfruit is also used for the preparation of vegetables, and curries or salads (Narasimham, 1990). Bulb of the jackfruit is eaten afresh and used in fruit salads and possesses high nutritional value-added products. The waste generated from jackfruit processing is also having potential to prepare some value-added products. The peel of the jackfruit can be alternative source of commercial pectin, activated carbon preparation, adsorbent to remove the various harmful dyes and metal ions from aqueous water and also useful to generate bio hydrogen, biogas and ethanol. The seed can be utilized as colorant in textile industry and also in pharmaceutical it is useful for the preparation of Fast Dissolving Tablets. The latex can be utilized as dental filling material (Kalse *et al.* 2022).

The jackfruit is a very seasonal crop that is a rich source of many minerals, proteins, and carbohydrates. Jackfruit is rich in several minerals, including vitamin A, vitamin C, thiamin, riboflavin, calcium, potassium, iron, sodium, zinc, and niacin. The jackfruit has been noted since ancient times because of its medicinal properties and the aforementioned chemical compositions. Jackfruit has a wide variety of physicochemical content, which are thought to contribute to health benefits for human beings. The advantageous physiological effects might also help prevent a number of illnesses (Prasanna *et al.* 2020).

Due to inadequate post-harvest infrastructure, such as processing, handling, transportation, and storage, a large amount of jackfruit production especially that grown during the rainy season (June–July) goes to waste. The necessity of processing jackfruit at this stage of mature fruit has attracted increasing attention to prevent the rotting of this miracle fruit because the sensory properties of bulbs and seeds were reported very high during this period. If the fruit can be preserved at this stage, this product could be used as a raw material throughout the year.

A significant amount of jackfruit is wasted since there aren't enough handling and processing tools available in a timely manner, necessitating postharvest technology intervention in jackfruit processing. Because of the jackfruit's thick and tough skin, manual unit activities like peeling, chopping, and coring are exceedingly challenging (Nelluri *et al.* 2021).

The waste associated with jackfruit production and consumption can be reduced by 80% thanks to a recent significant development in post-harvest technologies and machinery. In addition, it is feasible to produce a variety of unique value-added jackfruit waste products, including rind, seed, and latex, which will benefit jackfruit processing businesses. The various value-added jackfruit products are included in this review, along with freshly developed post harvest technologies.

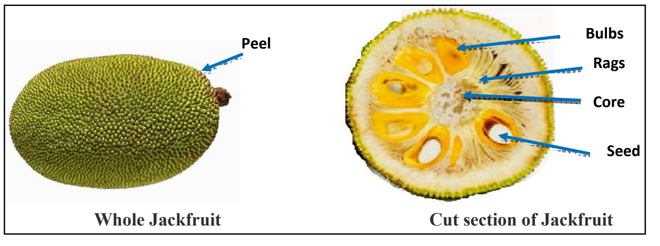


Fig. 1: Jackfruit Parts

Chemical Composition of Jackfruit

Jackfruit is rich in several minerals, including vitamin A and C, thiamin, riboflavin, calcium, potassium, iron, sodium, zinc, and niacin. It is low in calories with 94 calories per 100 g (Mukprasirt *et al.* 2004). The phytonutrients lignans, isoflavones, and saponins, which have numerous health advantages, are abundant in jackfruit which is having anticancer, antihypertensive, antiulcer and antiaging properties. Thus, it can lower blood pressure, combat stomach ulcers, and slow down the aging of the cells that give the skin a youthful, energetic appearance. It can also protect the body from producing cancerous cells. Niacin, also known as vitamin B_3, is another component of jackfruit and is important for the metabolism of energy, the health of the nervous system, and the production of a few hormones. 4 mg of niacin are present in 100 g of jackfruit pulp (Soobrattee *et al.* 2005). Jackfruit bulbs have a high nutritional value and contain 18.9 g of carbohydrates, 0.8 g of minerals, 30 IU of vitamin A, and 0.25 mg of thiamine per 100 g (Samaddar, 1985). The different nutritional properties of jackfruit and seed is shown in Table 1.

Table 1: Jackfruit Nutritional Composition (100 g edible portion)

Sl. No.	Composition	Young fruit	Ripe fruit	Seed
(A)	**Proximate Analysis**			
1	Water (g)	76.2-85.2	72.0-94.0	51.0-64.5
2	Protein (g)	2.0-2.6	1.2-1.9	6.6-7.04
3	Fat (g)	0.1-0.6	0.1-0.4	0.40-0.43
4	Carbohydrate (g)	9.4-11.5	16.0-25.4	25.8-38.4
5	Fibre (g)	2.6-3.6	1.0-1.5	1.0-1.5
6	Total sugars (g)	—	20.6	—
(B)	**Minerals and Vitamins**			
1	Total minerals (g)	0.9	0.87-0.9	0.9-1.2
2	Calcium (mg)	30.0-73.2	20.0-37.0	50.0
3	Magnesium (mg)		27.0	54.0
4	Phosphorus (mg)	20.0-57.2	38.0-41.0	38.0-97.0
5	Potassium (mg)	287- 323	191- 407	246
6	Sodium (mg)	3.0-35.0	2.0-41.0	63.2
7	Iron (mg)	0.4-1.9	0.5-1.1	1.5
8	Vitamin A (IU)	30	175-540	10-17
9	Thiamine (mg)	0.05-0.15	0.03-0.09	0.25
10	Riboflavin (mg)	0.05-0.2	0.05-0.4	0.11-0.3
11	Vitamin C (mg)	12.0-14.0	7.0-10.0	11.0

(Arkroyd and others 1966); Narasimham 1990; Swami et al., 2012).

Traditional Medicinal Uses

There are multiple medical uses for the fruit and other parts of the jackfruit tree. The pulp and seed are used as a cooling tonic and a treatment to counteract the effects of alcohol on the body in China. Ash from jackfruit leaves is frequently used as a therapeutic remedy for ulcers, while roasted seeds are thought to have aphrodisiac characteristics. When vinegar and latex are combined, glandular swelling and snake bites are helped to recover. The root and its extract are well-known for treating diarrhoea, asthma, and skin conditions (Morton *et al.* 1965). Jackfruit is effective against a number of illnesses, including leprosy, ulcers, constipation, heart disease, and rheumatism, according to renowned Ayurvedic and Unani practitioners (Mukherjee, 1993; Devaraj, 1985). The beneficial effects of leaves and stem bark in the treatment of anaemia, asthma, dermatitis, and coughs (Balbach and Boarim, 1992). It has a healthy quantity of potassium (303 mg/100 g), which lowers blood pressure.

Post-harvest Handling Practices

There are many difficulties for the post-harvest handling and storage of jackfruit as discussed in Table 2. Jackfruit can be harvested when it is immature or ripe, but care should be taken that it should not undergo any mechanical harm during its picking. Total soluble solids (20–30 ° Brix) and titratable acidity (0.19–0.50 g/L of malic acid) are key factors in determining quality of fruit during its ripening and the distinctive aroma of the jackfruit also detected at this ripening stage.

Jackfruit can be harvested and then placed on coir net platforms with the cut end pointing down to keep the latex off the fruit's surface. The fruit can be categorised based on size because larger fruits often yield larger bulbs than smaller fruits. After sorting and grading, rinsing with chlorinated water is a common phyto-sanitation practise used to remove dirt, foreign objects, latex, stains, and field contamination. Fruit must be properly rinsed after being washed in chlorinated water to eliminate extra moisture from the surface. Mature fruit can be allowed to ripen in the packhouse, while immature fruit should be maintained for 3–4 days at room temperature. The Physiological, physicochemical and physical properties of ripe jackfruit bulbs shown in Table 3.

Table 2: Different post-harvest handling practices & problems for jackfruit

Sl. No.	Unit operation	Postharvest problem	Remedial measure	Tolerance	Preventive action
1	Fruit Inspection	(a) Uneven ripening	(a) Sorting and Grading of fruit	(a) Too soft affecting the texture of the fruit	(a) Follow proper harvesting index
		(b) Infestation with fruit boring pests	(b) Rejecting contaminated fruit and switching to infield bagging	(b) 10% infected area	(b) spraying pesticides before harvest
2	Ripening	Non uniform ripening and over ripening	Use of ethylene gas to ensure uniform ripening	Within the same fruit and at least 50% ripe fruit shall be available for further handing from each fruit lot	Appropriate adoption of alternative indices and grading protocols
3	Cleaning	Probability of contamination as a result of poor wash water quality	Chlorination to adequate level (at 100 ppm) and appropriate surface drying	10% defective fruit	Ensuring hygienic water for cleaning
4	Cutting	Outer peel is hard to cut	Use mechanical cutter	—	Apply coconut oil on blade to avoid rusting
5	Separation of bulbs	• Microbial contamination from un-hygienic handling • Excessive physiological stress due to use of blunt edged knives • Excessive temperature abuses during handling	Personal hygiene of paramount importance, use of appropriate knives with sharp edge made up of food grade SS and maintenance of handling temperature of 18–28°C	Zero tolerance in terms of personal hygiene, quality of metallic devices	Follow standard plant hygiene measures
6	Bulb packaging	Biological hazards can occur due to wrong use of commodity specific selectively permeable packaging films and also incorrect setting of O_2 and CO_2 concentrations within the packages	Use of optimal packaging films and maintenance of appropriate fill weight and head space within the packages	O_2 level not below 2% and CO_2 level not beyond 6%	Adoption of stringent modified atmosphere packaging, and testing of packaging failure on regular basis
7	Marketing	Temperature abuses during retail marketing can cause potential biological hazards	Strict adherence to storage temperature	Higher and lower temperature shall not fluctuate by more than 2°C	Establishment of authentic cold chain at bulk storage and related marketing level
8	Storage of fruit	Sub optimal storage temperature causing spoilage	Pre cooling is recommended and storage at moderate temperature 10–12°C	Higher and lower temperature not exceeded by 2°C	Adoption of sound cold room maintenance and management

Table 3: Physiological, physicochemical and physical properties of ripe jackfruit bulbs (JFBs)

Sl. No.	Paramenter	Value	References
1	Respiration rate at 20 °C	20-25 (mg CO_2/kg h)	Saxena *et al.* (2008)
2	Ethylene production	0.6-0.7 (ppm)	
3	Firmness	45 (N)	
4	Total soluble solids (TSS)	20-35 (°Brix)	Souza *et al.* (2011);
5	pH	4.8–5.8	Ong *et al.* (2006)
6	Specific heat	2.70–3.92 (kJ/kg °C)	Souza *et al.* (2011)
7	Thermal diffusivity	5–85 (°C m^2/s)	
8	Density	1020 (kg/m^3)	
9	Hue	83–87	Vargas-Torres *et al.* (2017)
10	TSS, Acid ratio	54–134	Jagadeesh *et al.* (2007)
	Physiological disorders of jackfruit		
11	Chilling injury (CI) Jackfruit	10–12 °C	Saxena *et al.* (2011)
13	Symptoms of chilling injury to bulb	Pulp browning and poor flavor	
14	Immature or overripe fruit	Non-uniform ripening within the fruit	
12	Chilling injury (CI) to Jackfruit bulb	< 5 °C	Sally *et al.* (2011)

1. Grading of Jackfruit

The immature, over-ripe, damaged and misshapen fruits removed from the desired lot. Grade the fruit according to its weight i.e. Large fruit: 16 kg and above; Medium: weighing 8 kg to 16 kg and Small: weighing below 8 kg. After Grading wash the fruits using chlorinated water (100 ppm) to remove dirt, latex stains and any field contamination. Drain fruits properly to remove excess moisture from the surface of the fruit for further processing or storing.

2. Fruit Ripening

Jackfruit is a climacteric fruit that is extremely perishable. When jackfruit is harvested, there is significant changes in colour, texture, and flavour take place (Singh *et al.* 2015; Fernandes *et al.* 2011; Ong *et al.* 2006). When jackfruit is ripening, uneven ripening is a significant issue, especially with large fruit. As the portion of the fruit closest to the cut end may ripen earlier than that at the distal end, the ripening may be uneven amongst fruits or even within the same fruit. The most recent method of ripening unripe jackfruit involves keeping it in ripening chambers to encourage ripening. The ripening process can be sped up by adding ethylene (50 ppm) at a temperature of 25 °C. The fruit may only be exposed to ethylene for 24 hours, after which the chamber doors may be opened to allow natural ripening in ambient conditions. The fruit ripens in 3 to 4 days after being exposed to ethylene gas. Prior to pre- or minimal processing, jackfruits should be ripened fully to achieve optimum aroma, sweetness, taste and eating quality.

3. Fruit Cutting

Cutting jackfruit is an extremely challenging task. Jackfruit is traditionally chopped with a big knife called a *"Koyata,"* which increases the risk of damage and injury. Traditionally fruit cut by using large knives in half lengthwise. Latex may exude from the cut surfaces when extracting the flesh. Apply the vegetable oil on hands, knives and work surfaces to make it clean-up easier. Carve out the sticky central core. Scoop out the individual fruitlets (bulbs). Sort bulbs according to the required size, maturity and colour. Only full bulbs, (not half or partly cut) are recommended for marketing. Seed can be removed by cut the bulbs.

4. Processing of Jackfruit

Depending on the ripeness, jackfruit can be eaten as a fruit or a vegetable. In contrast to the ripe fruit, which is appreciated as a delicacy, tender and unripe jackfruit is frequently eaten as a vegetable. The different products prepared from mature and imature jackfruit is shown in Fig. 2.

(a) Jackfruit Chips

One of the oldest techniques for cooking food in oil or frying imparts distinct fried flavours and textures to meals. During frying, a number of chemical reactions take place, including starch gelatinization, protein denaturation, surface browning, fast water evaporation, and oil absorption. The product improve palatability and shelf life of the product. However, the latest consumer trends toward healthier and low-fat food products are making fried foods unsuitable. Acrylamide (46.2–2,431.4 μg/kg) which is food toxicant occurred in jackfruit chips when used deep fried method (Shamla *et al.* 2019).

The need to reduce cholesterol, calories from fat, and oil consumption has been highlighted by consumers' rising health consciousness (Bouchon *et al.* 2004). So that there are different frying techniques used for the preparation of low fat and healthier jackfruit chips as shown in Table 4.

Nowadays, the two methods most typically used to prepare jackfruit chips are hot air-drying (AD) and frying. The chips produced by frying have a tasty, crispy texture, but excessive oil absorption is unavoidable and is not ideal for your health. Despite the lower manufacturing costs of air drying, the extended drying times have a negative impact on the fruit colour, nutritional value, and texture quality of the chips (Saxena *et al.* 2012; Taib *et al.* 2013). The

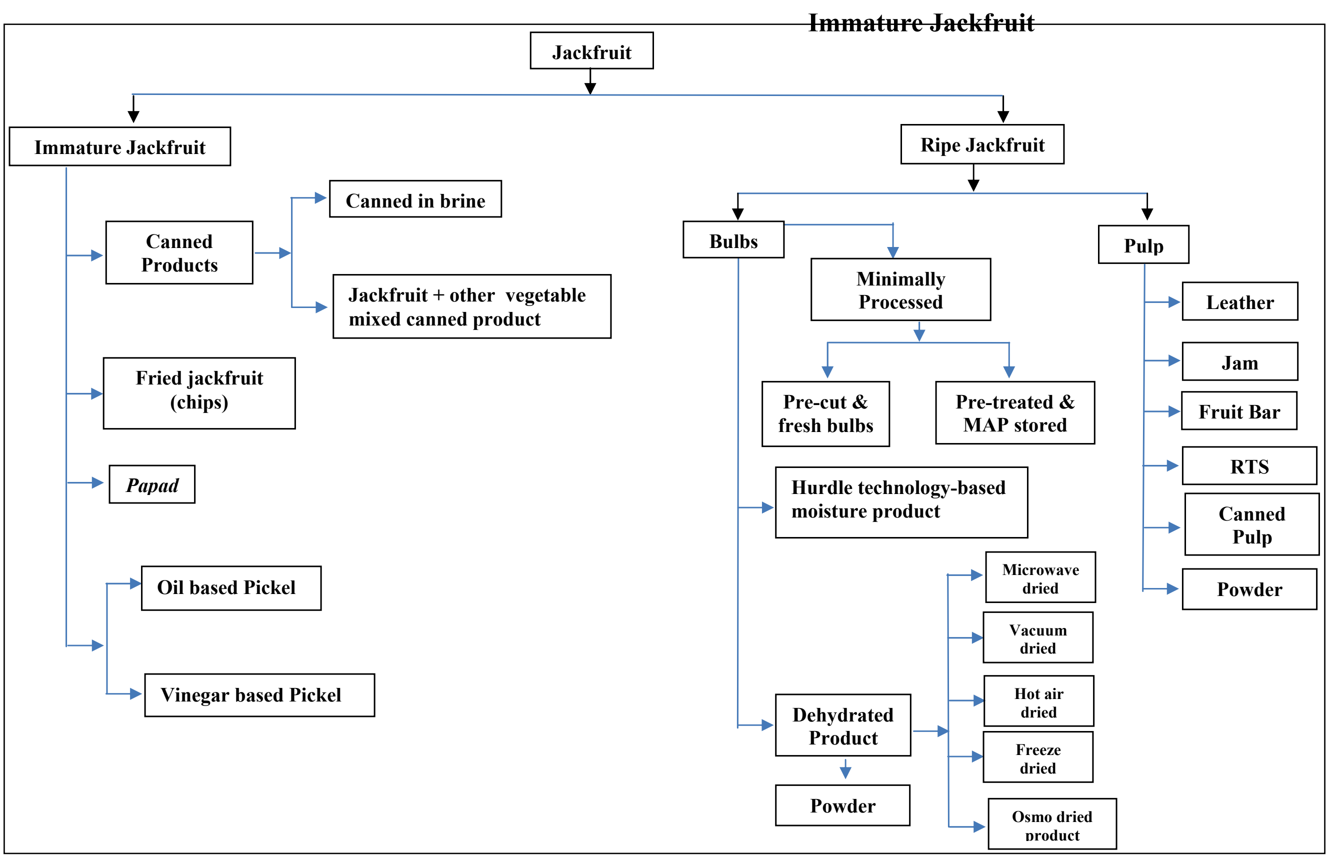


Fig. 2: Processing of Jackfruit for preparation of different products

Table 4: Preparation of jackfruit chips by using different techniques

Sl. No.	Frying process	Cutting Size	Pretreatment	Oil used	Drying System	Reference
1.	Deep frying	4 × 2 cm slices	Blanching 10 min (95°C)	Palm oil	Tray dryer 70°C for 1 hour	Molla *et al.* 2008
2	Pan frying	0.5 to 0.6 cm	Blanched 2.0 % of salt concentration	Vegetable oil	—	Maheshwari *et al.* 2020
3	Vacuum frying (90°C, 25 min)	—	Hot water blanching	Vegetable oil	—	Maity *et al.* 2014
4	Instant controlled pressure drop-assisted freeze drying	—	FD- 0.1 kPa	—	FD-DIC	Yi *et al.* 2016a
5	Explosion Puff Drying (EPD)	3.0 × 1.5 × 1.5 cm slices	Freeze drying @50 Pa.	—	(FD-EPD)	Yi *et al.* 2016b

FD-DIC - Instant controlled pressure drop-assisted freeze drying; Combined freeze-explosion puff drying (FD-EPD).

jackfruit chips is popular in diet of modern consumer due to its taste, rich in many phytonutrients and pleasant crispy mouth feel (Zou *et al.* 2013).

The chips can be produced with help of different technologies such as deep fat frying, vacuum frying, freeze drying, steam puff drying, and microwave vacuum drying. Besides these, a novel technology called Explosion Puff Drying (EPD) also used which has some unique advantages. One of the most crucial characteristics for fruit chips is a typical porous structure and an appealing crispy texture, flavor, color, rehydration all of which are enhanced by the EPD (Du *et al.* 2013). Only the FD-EPD dried chips showed a volume expansion impact, which was consistent with their well expanded honeycomb microstructures and rapid rehydration. Additionally, FD-EPD dried chips displayed relatively low hardness, indicating a puffy structure and a crispy feel and also showed comparatively significant ascorbic acid, phenolic, and carotenoid retentions (Yi *et al.* 2016). The absorption of oil while frying can be reduced by using hydrocolloids which also helps to maintain the quality of the fried jackfruit chips (Maity *et al.* 2015).

(b) Jackfruit Seed flour

The three most popular techniques for making jackfruit seed flour are mechanical peeling, heat processing, and lye peeling. In Lye peeling procedures, Jackfruit seeds are treated with 3% NaOH for 3 minutes, making it easier to remove the thin, brown spermoderm and white cotyledons that are produced. The seeds are then chopped and dried at 50°, and the prepared seed then pin-milled for producing seed flour.

Jackfruit seeds were boiled and cooled using a heat processing procedure. Manual removal of the seed's outer skin and seed coat. The seed is then sliced into three or four pieces, dried at 50°C in a tray drier, ground in a flour mill, and packed (Munishammana *et al.* 2007). Utilizing a knife, the outer, brown layer of the seed is removed after keeping it in water for 10 minutes when using the mechanical method. Then it was cut into slices, dried at 50°C, processed in a pin mill, and flour was prepared (Praveenasri *et al.* 2006).

(c) Tender Jackfruit

Tender jack fruit has 2.6 grammes of protein, 4.4 grammes of fibre, 50.1 mg of calcium, 97 mg of phosphorus, 1.5 mg of iron, 206 mg of potassium, and 11 mg of vitamin C per 100 grammes of edible fruit. Tender jackfruit is utilised as a fruit, vegetable, and a replacement for staple foods. Antioxidants which are present in tender jackfruit have the ability to slow down or stop the oxidation process (Ambily *et al.* 2019).

Tender jackfruit valued highly for its distinct qualitative characteristics and is a commonly used as vegetable in many south Asian countries. However, because to its seasonal nature, high perishability, and limited technology for storage and transportation, its year-round availability is restricted. The Tender Jackfruit can be brined for at least six months in 75 micron standing pouches or glass jars with 8% salt strength. During the off-season, the brined, tender jackfruit can be transported easily and also it can be utilised as a vegetable in curries (Marak *et al.* 2019). According to study, thermal processing produced tender jackfruit that was microbiologically safe and could be securely stored for two months (Pritty *et al.* 2020).

(d) Drying of jackfruit bulbs

Fruits and vegetables are frequently dried because it reduces volume of product, decreases the costs of packaging and transport, and is also microbially stable so increasing its shelf-life. However, the dried product must be of very high quality because poor drying practises could compromise its texture, colour, nutritional content, and rehydration properties (Nijhuis *et al.* 1998).

Jackfruit is traditionally stored for a long time by drying, but there are insufficient scientific studies on dried jackfruit. The combination or intermittent drying process having the benefits of combined drying processes and avoiding the drawbacks of a certain drying method (Kumar *et al.* 2014). Combination drying techniques have been shown to be more energy-efficient and produce qualitied dried material. There are some novel methods of drying such as hot air drying (Xu *et al.* 2013), osmo-convective dehydration (Kaushal & Sharma, 2016) and vacuum freeze-drying (Zhang, 2015), infrared drying (Bingol *et al.* 2014). The novel drying techniques for dehydration of jackfruit bulbs are shown in Table 5.

Table 5: Novel drying techniques used for jackfruit bulbs

Sl. No.	Drying technology	Drying condition	Drying characteristics	Result	Drying model fitted	Reference
1.	Infrared + Ultrasound	US, 80 W + IR 900W	T=250 min; drying rate 3.65g/(g.min), Deff = 3.89×10^{-9} m^2/s.	Retention of vitamin C and total phenolic content (TPC).	Midilli model for IR-US drying	Bengang *et al.* 2021
2.	Freeze drying + Hot air drying	100–300 Pa pressure and plate temperature 50 °C FD + 60°C HAD	FD for 6 h followed by HAD for 8 h (60°C)	Better rehydration ratio, shrinkage, texture, color values and sensory scores as compared to the hot air-dried crisps	—	Saxena *et al.* 2015.
3.	Microwave vacuum and convective hot air	MW- 321W, vacuum level of -65 cmHg, CD-60°C	Drying time 133 times faster than HAD @ 60°C.	Higher rehydration, good colour, appearance and aroma attributes.	Page's equation model	Taib *et al.* 2013
4.	Osmotic + Tray Drying	Osmosis 3h + Tray drying 60°C.	40°B & 60°C gives goo result	Retain yellow colour, Store for 12 months	—	Swami *et al.* 2014
5.	Solar tunnel drying	Transparent plastic covered flat-plate collector	14 h, for 5% M.C.	Multi-layered NN approach used to predict the performance of the solar tunnel drier	Artificial Neural Network Modeling	Bala *et al.* 2005

HAD - Hot air drying; FD- Freeze drying; IR – Infrared; US – Ultrasound; MW – Microwave dryer; CD- Convective dryer.

Nutritionally, sound and health beneficial bakery products can be prepared by using jackfruit which will be new frontier that offers a wide array of possibilities in processing industries. The different Processed Products developed by using Jackfruit Seed and Bulbs are shown in Table 6.

Future food from Jackfruit

According to recent research, jackfruit seeds and bulbs have a strong potential to be utilised as a nutritious and make unique food products due to their exceptional sensory features.

Table 6: Different Processed Products developed by using Jackfruit Seed and Bulb.

Sl. No.	Portion used	Product	Particular	Result	References
(A)	**Fresh Bulb Products**				
1	Bulb	Fresh jackfruit bulbs	Vacuum preserved (760 mm lbs)	Stored at Refrigeration for 15 days	Ukkuru and Pandey, (2005)
2	Bulb	Freezed jackfruit bulbs	Freeze at -29°**C**	Stored at -18° C for 12 months	Yi *et al.* (2016)
3	Bulb	Jackfruit candid products	Impregnated with cane sugar and glucose and subsequently drained and dried	Stable at room temperature	Ukkuru and Pandey, (2005)
4	Bulb	Candid products	Osmo air dried; osmotic dehydration 30 min in 70°Brix at 50°C (20% glycerol for soft verities)	Nutritious and stored at room temperature	Vazhacharicka *et al.* (2015)
5	Bulb	Jackfruit jelly	Pulp extract: sugar: acid: Jelly = 1:1:0.6:0.8	Nutritious jelly	Apsara (2002)
(B)	**Baked Product**				
6	Seed Flour	Bread	5 % blending with Maida.	High protein and carbohydrate content, good water and oil absorption ability	Tulyathan *et al.* (2002)
7	Seed Flour	Bread	25 % blending with Maida	Crude fiber content of the product increased	Butool & Butool (2015)
8	Seed Flour	Bread	25 % blending with Maida	Nutritionally higher carbohydrate, fat, protein, and crude fiber content	Hossain (2014)
9	Seed Flour	Biscuit	20 % blended with other ingredients	Increase in swelling ratio, solubility, flour dispersibility and viscosity	Butool & Butool (2015)
10	Seed Flour	Cake	5-15 % Seed flour	Increase in protein and reduction in fat content	Arpit & John (2015)
11	Seed Flour	Chocolate cake	5-25 % Seed flour	Improved dietary fiber and anti-oxidant activity	David (2016)
12	Seed Flour	Composite Cake	10-30% Seed flour	Better crumb, texture and nutritional characteristics	Khan *et al.* (2016)
13	Seed Flour	Muffins	10-20 % Seed flour	Specific gravity increased and viscosity decreased	Siti Faridah & Noor Aziah (2012)
14	Seed Flour	Low calori Cake	16 % Seed flour	Reduced calorie chocolate cake (34 % calorie reduction)	

15	Seed Flour	Jam	300g pulp, 900ml water, 300g sugar. 18g citric acid and 20 ml pectin for 10 to 15 minutes boiled in open pan method	High fibre, Protein rich jam	Eke-Ejiofor *et al.* 2013
(C)	**Extrudate Product**				
16	Bulb and Seed Flour	Noodles	Noodles prepared by using Maida flour+ JF bulb flour + JF seed flour in ratio of 50:10:40	High nutritional quality noodles can be prepared.	Veena Kumari *et al.* 2015
(D)	**Fortified Product**				
17	Seed	Karasev and Jamun	25 and 50% blending	Decreased fat absorption capacity	Sri Rajarajeshwari & Prakash (1999)
18	Seed	Cereal bar	30 – 40 % blending	High fiber content, better sensorial characteristics	Santos *et al.* (2011)
19	Seed	Cereal bar	15 % blending	Preserved hardness and crispness	Torres *et al.* (2011)
20	Seed	Snack bar	35-45 % blending	Increased protein content	Meethal *et al.* (2017)
21	Seed	Papad	Vacuum fried Papad	Wraped in paper and stored at 20–30°C for 6 months	Kamath, (2008)

1. Chocolate aroma in food formulations

A characteristic chocolate aroma developed when jackfruit seeds are fermented and roasted similarly to cocoa beans (Spada *et al.* 2017). Recently, it was discovered that the synthesis of pyrazine (odor-active volatiles) in jackfruit seed flours depends on the composition of the amino acids and the bioavailability of the sugars during fermentation (Spada *et al.* 2021). Pyrazines are dominant odor-active compounds in roasted jackfruit seed flours, cocoa beans, and cocoa powder (Afoakwa, 2010; Al-Duais *et al.* 2009; Tran *et al.* 2015). Beverages using fermented jackfruit seed flours contain cocoa volatiles. Future food formulations may use fermented jackfruit seed flours as a full or partial ingredient to enhance chocolate flavour (Spada *et al.* 2022).

2. Food Colour

There is now rising demand for natural food colours because they are healthy. Synthetic colouring chemicals are prohibited due to their carcinogenic and teratogenic properties. It is well known that the genus Monascus' microorganisms create red pigments that can be used to colour food. The jackfruit seed can be used to create the natural red pigment. The extraction of red pigments from jackfruit seeds is also an easy and affordable method. As a natural food colourant, jackfruit seed powder made from dried, ground-up, and fermented seeds could be utilised (Sumathy *et al.* 2007).

3. Low GI Chocolates

The main component of chocolate is Cocoa which is rich in polyphenolic compounds. As an alternative to cocoa powder, jackfruit seed powder made from fermented jackfruit can be a great replacement. Foods with a Glycemic Index (GI) of less than 55 are categorised as low GI, those with a GI of 56 to 69 as medium GI, and those with a GI of more than 70 as high GI. Commercial chocolate has a GI of 70.8, however chocolate made with jackfruit seed flour has a GI between 43.6 and 44.8, placing it in the Low Glycemic Index group. In order to make chocolate with a Low Glycemic Index (GI), jackfruit seed powder can replace cocoa powder up to 10%, this makes the chocolate a healthy food that diabetics can consume (Miller, 1994). The developed chocolate is thermal resistance so that there is no any significant changes in characteristics of chocolate at room temperature (Ravindran *et al.* 2020).

4. Biofilm

The biodegradable film made from seaweed slurry and jackfruit seed starch which has excellent film qualities including water resistance (43.56%), elongation (0.01%), yield stress (1.1%), and tensile strength (2.69 MPa) (Yusmaniar *et al.* 2019). The mechanical property and transparency of film can be improved by adding plasticizer as a Glycerol and tensile strength can be improved by adding Lysozyme (Nurulain *et al.* 2019). The freshness of tilapia fish and shrimp was examined using a film made from jackfruit seed starch and grape anthocyanins. It is also possible to utilise this film as a visual indicator or smart packaging material to determine the degree of product freshness because the colour of the film changes as the quality of the fish declines (Leandro *et al.* 2020).

Jackfruit Processing Equipment's

The different unit operations that went into jackfruit processing included peeling, cutting, coring, removing the bulb, roasting the seeds, and dehulling the seeds. All of these unit operations are completed manually, which requires additional time and effort. jackfruit's having irregularity in shape and also very hard outer surface, so the manual cutting is the most time-consuming step in the processing of jackfruit.

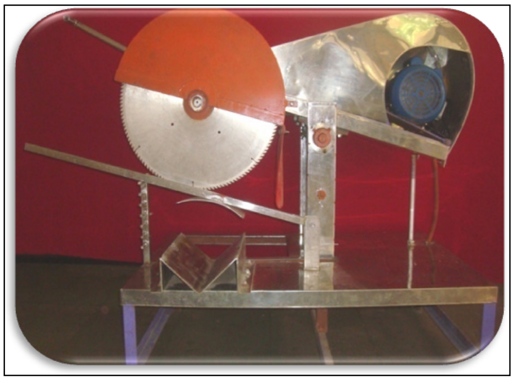
Thus, the development of appropriate machinery for such unit processes becomes necessary and helps in making jackfruit processing quicker and more effective. For industries to learn about different machineries used in jackfruit processing would be very helpful.

1. Jackfruit Cutter

Convectional method of jackfruit cutting is by using large knife which requires more energy, loss of whole bulbs and also there is chances of injury during cutting operation. To reduce bulb losses during cutting of the Jackfruit and for safety cutting there are number of jackfruits cutting devices are available in market. The Jackfruit cutter and Dresser were developed by Dr. Basaheb Sawant Konakn Krishi Vidyapeeth, Dapoli is shown in Fig. 3. With the help of these cutter, we can cut large number of Jackfruits in short period of time. The first is the Power Operated Jackfruit Cutter, which cuts about 60 jackfruit/h and second is the Hand Operated Jackfruit Cutter which cuts 10 fruits/h.

2. Jackfruit Cutting and Peeling Machine

This machine can process all sizes of tender jackfruit with the effective throughput capacity of 25 kg/hr. All food contact parts of the machine are of Stainless Steel- Grade 304. The machine is being capable of washing, peeling and cutting of tender jackfruit effectively. The capacity of chemical holding tank is 30 liters and a pump was used to create the turbulence



Motorized Jackfruit cutter

Hand operated jackfruit cutter

Fig. 3: Jackfruit Cutter

in tank. The peeling assembly consists of adjustable platforms to hold any size of jackfruit firmly (Length: 8 to 30 cm and diameter). The hollow shaft to spin the jackfruit on its longitudinal axis is driven by motor (3 phase), with provision to control its speed. Cutting assembly contain roller blades with serrations on the sharp edges which cut the jackfruit in slices of 4.5 cm (Rana, 2019). The jackfruit peeling and cutting machine and Vacuum fryer are as shown in Fig. 4.

3. Jackfruit Chips Cutting Machine

Before being fried, the fragile jackfruit bulbs are traditionally cut with a knife into thin slices. It takes a skilled person to prepare little slices. The jackfruit bulbs can be divided into thin slices using the jackfruit chips cutting machine.

4. Jackfruit Frying machines

The difficult operation process known as "frying" involves dipping the slices of jackfruit into heated vegetable oil, typically coconut oil, that is above the boiling point of water. The initial moisture content of the jackfruit slice (74 %) reduced during frying process (4) for making chips. The ideal moisture content of the jackfruit chips is 3-4% on wet basis. The slices are fried in edible oil; coconut oil is used in Kerala, while any refined vegetable oil such as sunflower oil can be used. Preferably, the ratio of jackfruit slice to oil should be 1:2.5 to 1:4. The dried slices are dropped into oil at a temperature of 160-180°C and stirred with narrow wooden stick. When the chips transform to a light-yellow colour, they are drained from the fry pan. At around 170°C, the required frying time is around 10 minutes.

Vacuum frying is a solution to the issues caused by excessive oil content that causes immediate rancidity and the health issues caused by the carcinogens released during frying. Lower than 100°C temperatures are used while vacuum frying. A benefit of vacuum frying is that the oil quality is preserved and it can be reused for more times.

Economics of Jackfruit Processing

One Jackfruit tree is thought to produce fruits that weigh between 5-7 kg on average. Jackfruits will be produced in amounts ranging from 21 to 28 tonnes per acre on an acre of land that produces 4,000 trees with 315 to 420 kg of fruit from each tree (APAARI, 2012). In light of the low price of one jackfruit at about ₹ 7.5 per kg, an acre will yield close to ₹ 2.0 for each season. Fig. 5 shows the yield of jackfruit from the one acre of Jackfruit Plantation. The yield of jackfruit is only used for processing to the tune of 40%, with the remaining 60% (or ₹ 1.22 lakh per acre) going to waste.

If we consider the economics jackfruit leather (Phanaspoli) and chips which was prepared in more than 95 % households. At the overall level, per

Fig. 4: Jackfruit Cutting and Peeling Machine **(a)** Vacuum Frying machines **(b)**

Fig. 5: Machineries used for Jackfruit and Seed Processing

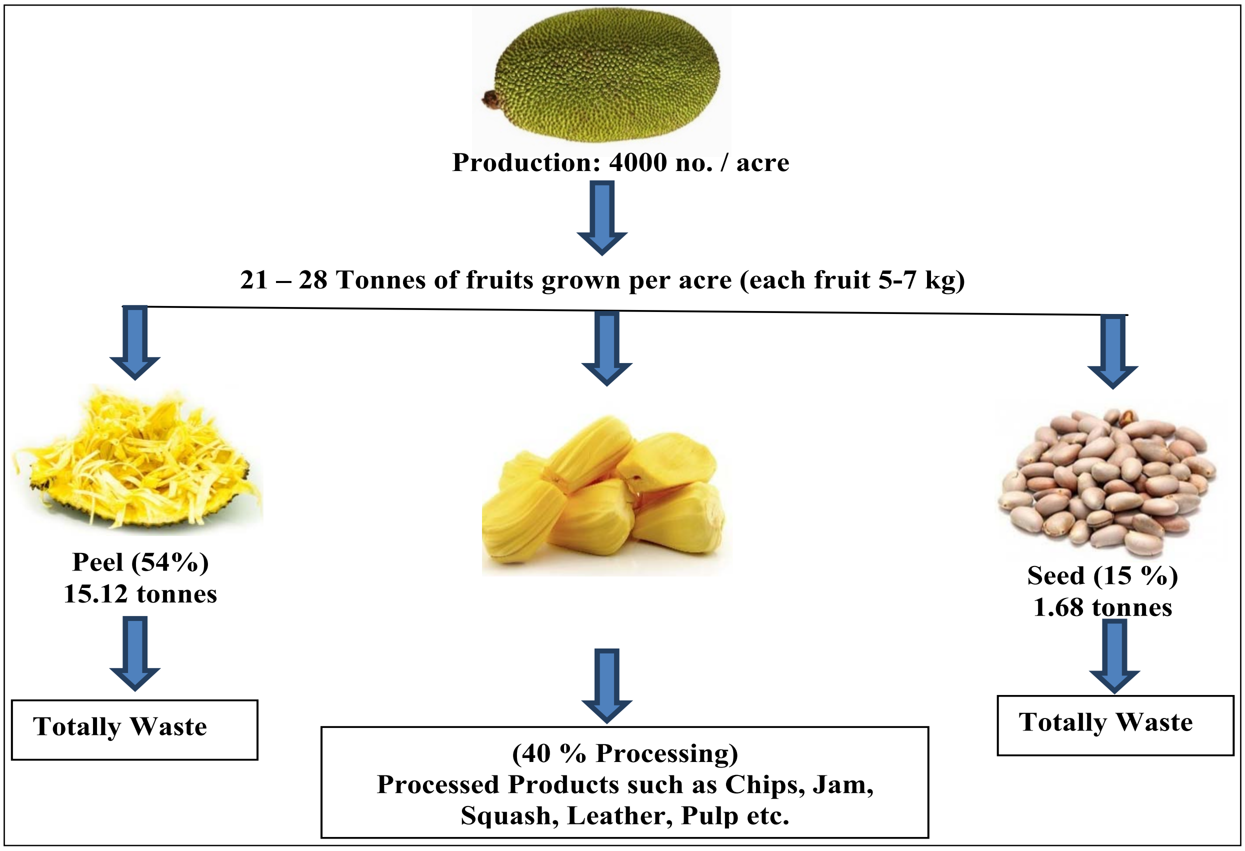


Fig. 6: Jackfruit yield from one acre of Jackfruit Plantation

household quantity and value realized in jackfruit processing for leather was 41.38 kg and ₹ 4669.10 and 98 kg and ₹ 14452.08, respectively. This revealed that sample households were supplemented in gross income from jackfruit processing. The capital investment per household was ₹ 10553.49 of which 18.51 % was fixed capital and 81.49 % was working capital. Of the total capital investment share of raw material was highest (62.16 %) followed by labour charges (19.69 %). In case of jackfruit leather and jackfruit chips benefit cost ratio were 2.13 and 1.67, respectively at the overall level. Net value addition was 262.70 % and 303.54 % in the same order. Thus, jackfruit processing was profitable subsidiary business activity for providing gainful employment and income to processing households (Roy *et al.* 1995; Burkill *et al.* 1997).

CONCLUSION

Jackfruit is rich in many nutrients like vitamin A, vitamin C, thiamine, riboflavin, vitamin B6, calcium, magnesium, phosphorus, potassium, manganese, zinc, dietary fiber, protein, carbohydrates etc. jackfruit seed is having high nutritional values. So, you must try to include the jackfruit in your diet also jackfruit is an important source of phytonutrients which are good for our health. Jackfruit is very important crop for food security. There is a lack of information on the post harvest technologies and economics of jackfruit, a situation which is surprising to many considering that the fruit is valued as a staple in times of scarcity in some countries. There is a distinct possibility of marketing the jackfruit products in other states of India as well as in foreign countries by using novel post-harvest processing machinaries and prepare new value added products.

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