



# Current status of post-harvest of jackfruit - potential for use and circular economy in Vietnam

**Vo Quang Minh<sup>1</sup>, Trinh Thi Thanh Thuong<sup>1</sup>, Nguyen Minh Thuy<sup>2\*</sup>, Tran Ngoc Giau<sup>2</sup>,  
Hong Van Hao<sup>2</sup>, Ngo Van Tai<sup>3</sup>**

<sup>1</sup>College of Environment and Natural Resources, Can Tho University, Can Tho, Vietnam

<sup>2</sup>Institute of Food and Biotechnology, Can Tho University, Can Tho, Vietnam

<sup>3</sup>School of Food Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

## Abstract

Jackfruit is a dicotyledonous compound fruit (*Artocarpus heterophyllus* L.) belonging to the Moraceae family that grows in many tropical countries in Southeast Asia, of which Vietnam is also a jackfruit growing country with large yields. In Vietnam, jackfruit mainly uses fresh citrus when harvesting ripe fruit. With high nutritional value, jackfruit segments are also processed into convenient products such as dried jackfruit, vacuum fried jackfruit... which have been provided in domestic markets. Many other parts such as jackfruit fiber, jackfruit seeds or young jackfruit fruit (accounting for about 68-72% of the fruit weight) are often discarded, even though they contain many components with certain nutritional value such as fiber, carbohydrates and bioactive compounds. With many health benefits mentioned, disposing of these ingredients will waste beneficial resources and will also be a burden to the problem of environmental pollution. Thus, in addition to using the main ingredient jackfruit for diverse processing, the auxiliary ingredients of jackfruit can also be used to create value-added products and extract antioxidant, phenolic compounds and organic acids. Adding value from jackfruit post-harvest waste can support sustainable solutions towards food security and nutrition. From these utilization methods, jackfruit growing areas can effectively use post-harvest jackfruit resources, minimize waste with appropriate technology, and develop a circular economy in accordance with the current development situation in the region and country.

**Keywords:** jackfruit, jackfruit by-products, processing, use, circular economy

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## 1. Introduction

Jackfruit (scientific name is *Artocarpus heterophyllus* Lam) is the largest fruit among the popular fruits, grown in tropical and subtropical regions. Jackfruit is grown throughout all provinces in Vietnam and is also found in Laos and Cambodia. Jackfruit is a large and tall tree, which can reach more than 30 m. Flowers are unisexual, monoecious. The complex fruit is large, 30-60 cm long, with a surface bristling with short spines [1]. Jackfruit is also one of the five main crops of Hau Giang province in Vietnam. Hau Giang's terrain is in the form of a basin, with areas along rivers and canals and roads that are often high and gradually lower in the distance. The riverside area is quite favorable for tidal irrigation during the dry season, but in areas farther from

the river, irrigation is more difficult. Hau Giang's climate and weather conditions have basic advantages that other provinces in the Mekong Delta do not have, such as few natural disasters, no direct storms, abundant light and heat, so it is very favorable for many types of plants and animals to grow. The hydrological regime of Hau Giang is governed by three factors including the tides of the Gulf of Thailand, the hydrological regime of the Hau River and local rain. These factors impact each period and each region differently, making Hau Giang's hydrological regime rich and diverse. According to Hau Giang Department of Crop Production and Plant Protection (2022), the whole province has 9,972.3 hectares of jackfruit cultivation area, of which 6,657 hectares (66.75%) of the area is fruit-bearing. Surveying over 30 jackfruit growing households in Hau Giang, the main

jackfruit variety grown is the yellow-fleshed Thai jackfruit variety, concentrated in Chau Thanh district, Nga Bay city, Chau Thanh A, Phung Hiep district, Long My and Vi Thuy towns.

The jackfruit tree bears fruit after three years of age and its fruit is a complex, edible fruit. In recent years, implementing the policy of restructuring crops and livestock, associations and organizations in Vi Trung commune (Vi Thuy district, Hau Giang province) have mobilized and oriented farmers to implement many models that bring high economic efficiency. In Vietnam, jackfruit has high commercial value. Mature jackfruit has an oval shape, large size 30–60 cm x 20–30 cm, average weight from 3.5 kg to 10 kg and sometimes reaches 25 kg. Usually, jackfruit bears fruit around mid-spring and ripens in late summer (around July to August every year). When ripe, the skin is still green or slightly yellow. Ripe fruit flesh is yellow, has a sweet taste, a strong aroma that is easy to distinguish from other fruits and has many seeds [1]. This fruit is popular due to its beneficial health effects when used. 100 g of ripe jackfruit contains 72.0-94.0% water, 16.0-25.4% carbohydrates, 1.2-1.9% protein, 0.1-0.4% lipid, 1.0-1.5% fiber, along with good amounts of thiamine, vitamin A, calcium, phosphorus, potassium and magnesium. Jackfruit also contains large amounts of phytonutrients, so it has the ability to prevent cancer, reduce blood pressure and reduce the risk of diabetes [2]. However, because it is a fruit with a high respiration rate, it is very susceptible to post-harvest damage, so proper management can prolong their storage life and use them for other processing purposes. Localities in many countries used jackfruit to cook curry, make smoothies... and some commercial food products with high added value such as drinks, jams, ice cream, dried and extruded products. The use of jackfruit as a vegan meat substitute has also become popular in Western countries due to its meat-like texture and ability to absorb flavors [3]. Other parts of the jackfruit tree including the bark, leaves, roots, flowers, pulp and seeds all have their own properties and health benefits. Fresh jackfruit leaves can be harvested and used as medicine immediately afterward. Some places use jackfruit wood (fresh or dried) as a sedative [1]. Many scientific research results have demonstrated the potential health benefits of bark, seeds, leaves, roots of jackfruit tree in preventing and minimizing chronic diseases such as obesity, diabetes, cancer and some digestive problems [3].

Furthermore, the waste products from jackfruit processing are also edible. Not only are they processed directly and sold as separate products, but they are also used in a variety of recipes, for example as nut flour. Developing value-added products from jackfruit and jackfruit waste can contribute to rural development, increase people's income and reduce hunger and poverty, while also eliminating challenges that are hindering development of the jackfruit processing industry and highlight the potential of this industry for sustainable economic and agricultural development. This activity also exploits circular economy products, enhances product value, makes the most of resources from by-products and maintains the ecological environment.

## **2. Post-harvest handling for the whole fruit market**

Jackfruit sold to domestic and international fruit markets must be properly handled from harvest to retail, with important stages including: Harvesting in the field →

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Packinghouse → Sorting, Washing, Rinsing → Grading → Packaging → Storage → Transportation → Cooking → Sales (wholesale and retail)

### **2.1 Pre-harvest factors affect post-harvest quality**

#### **2.2.1 Fruit development and maturity**

Fruit growth and development are measured by fruit diameter, weight, length and circumference, as well as the nature and extent of the spines [4]. The spines are well developed, spread out and become less sharp as the jackfruit matures [4]. Jackfruit received from the farm also needs to be inspected to ensure satisfactory size and quality. Nine developmental stages of jackfruit (cv. 'Tekam Yellow'), starting from the appearance of the inflorescence were identified by Mijin and Ding [5]. Growth stages 1 to 5 involve the development of inflorescences. Pod formation begins in the sixth growth stage, which includes the formation of a thick, blunt spiky shell. At this stage, the three parts of the syncarp are clearly distinguished; the first zone consists of the edible flesh, the second zone is the white spongy part associated with the syncytium shell, and the third zone consists of the spiny structure covering the syncytium shell. At the seventh stage of growth, a change in peel color is observed from dark green to green and an increase in the size of seeds and pods. The eighth stage shows the color of the fruit changing to light yellow. During this stage, the absence of a characteristic aroma and the presence of starch granules in the fruit skin indicate that the fruit is not yet mature. At the final stage, the color of the fruit skin turns yellow brown, with almost no starch granules remaining, proving the conversion of starch into sugar.

However, according to Palipane and Rolle [6] and Ramli and Ahmad [7], the maturity index of jackfruit composed 8 stages as follows: the fruit ripens about 12-16 weeks after blooming; Fruit color changes from green to light yellow green; When you tap the fruit with your fingers, it will make a hollow, dull sound; Fruit spine is well developed and evenly spaced; The last leaf of the stem is yellow; Fragrant development; The number of spines in the outer shell decreases and the spines become flatter and The length and circumference of the fruit increase. The fruit should be harvested by cutting from the stem using sharp bladed equipment. If the fruit is on a high tree, use a rope to tie a sack around the fruit, cut the stem and gently lower the fruit to the ground [6]. Accurate determination of ripeness and best harvest time as well as precise harvesting practices help minimize fruit losses [8].

Kishore [9] divided the fruit maturation process into four sub-stages. The first stage of maturation is a change in fruit color to light green or light yellow, seed color to light brown and flesh color to yellow, along with flat spines. At the advanced stage of maturity, the flower stem color changes to light yellow, stops secreting pus, and the fruit flesh begins to turn fleshy and light yellow. The third stage is the maturity of the fruit for commercial picking, during which a hollow sound is made when tapped, the spines are bent at moderate pressure, and the seeds are fully mature. The final stage is called over-ripe fruit, which involves softening of the seed membranes leading to loss of textural uniformity, complete flattening of the spines and sometimes germination of the seeds inside the fruit (vivipary).

### 2.2.2 Maturity index

Accurate determination of maturity stage is important for harvesting high-quality fruit and reducing post-harvest losses. Maturity time depends on a number of factors such as tree age, location and weather conditions. In most countries where large quantities of jackfruit trees are grown, farmers determine the fruit's maturity indicators including change in skin color from light green to brownish green or yellow, flat thorns on the fruit surface, and development of flavor characteristic and the number of spines is reduced on the fruit surface [10]. When impacted on the fruit, a dull and hollow sound is often heard. Malaysians estimate by listening to the hollow sound, observing the color change of the leaf stalks and calculating the hardness of the spines and the color of the fruit [6]. In India, farmers judge maturity based on hollow sound and fruit shape, while in Bangladesh, the farmers assessed the optimal maturity of jackfruit based on the time from flowering, color change and thorn development [11]. However, Kaur *et al.* [12] said that the change in fruit color is not a reliable indicator of maturity because the skin color can also vary depending on the variety. In Vietnam, it takes about 5 months from flowering to mature jackfruit. Jackfruit at this stage has swollen spines, the skin changes from young green to yellow green, the sap is liquid and clear, and when you clap your hands on the surface of the fruit there is a popping sound. If transported long distances, the fruit will be harvested at the maturity stage. If the fruit for sell or eat right away, it should be waited until the fruit has a fragrant aroma before harvesting.

### 2.2 Harvesting

Jackfruit is harvested at different stages of ripeness depending on intended use and market demand. Fruits are often classified based on their size and appearance. For ripe fruits, jackfruit with orange flesh is more popular with consumers because of its good quality. The Jackfruit should be harvested by cutting from the stem using sharp bladed instrument. If the fruit is on a high tree, use a rope to tie a sack around the fruit, cut the stem and gently lower the fruit to the ground [6]. The study by Saha *et al.* [13] showed that the best commercially mature jackfruit at 100 days after fruit set. At that stage, spine density is low and widespread, their preservation time is also higher (6 days) compared to other harvest times. Time required for fruit to reach maturity when harvesting fruit at 100, 110, 120 and 130 days after fruit set. Fruit harvested early at 90 days after fruiting often does not ripen evenly. Time required to ripen, storage time after ripening and total storage time (6 days) were recorded for fruits harvested at 100 days after fruit set [13]. Mijin *et al.* [14] recommended that the optimal harvest period for Tekam Yellow jackfruit is 14 weeks after anthesis for local markets and 12 weeks after anthesis for long distant markets. In Vietnam, farmers often harvest jackfruit at the appropriate time of 21-22 weeks after fruiting or 160-180 days after anthesis.

### 2.3 Washing

The fruits are sorted, washed and drained at the packing house. Washing should be done with chlorinated water 100 ppm to remove dirt, foreign matter, latex stains and other contaminants in the field. After washing, the fruit must be drained to remove excess moisture from the surface of the fruit.

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### 2.4 Grading

Fresh fruit sold on the market must be classified according to technical standards agreed upon by the buyer and supplier.

### 2.5 Packing/Transportation

Whole jackfruit is a large fruit that needs to be properly packaged for ease of handling and also to protect against serious mechanical injury. Depending on the market area, fruit should be packaged in sturdy corrugated cardboard or plastic boxes, individually or in pairs. All fruit should be transported to market at an unripe stage to avoid spoilage. Shipping can be done by non-refrigerated truck or pickup truck.

### 2.6 Ripening physiology of fruit, ethylene biosynthesis and respiration rate

Jackfruit must be ripened before retail sale. Natural ripening can occur by keeping the fruit at ambient temperature for about 3-4 days. However, uneven ripening is the main problem in natural ripening, especially for large fruits. Therefore, artificial ripening is recommended to achieve more uniform ripening. Induction ripening can be accomplished by keeping the fruit in a static or sealed ripening chamber, equipped with an ethylene gas tank and a flow rate controller. Ethylene gas at a concentration of 50 ppm should be discharged into the chamber at a temperature of 25°C. After 24 hours, the chamber must be opened to continue the ripening process at ambient conditions. The fruit can ripen 3-4 days after induction. Fully ripe fruit is indicated by a very strong aroma and soft fruit. Well-ripe fruit has good quality in terms of aroma, texture (crispness), sweetness, with a total soluble solids content of about 24°Brix, a total sugar content of about 15-17% and a titratable acidity of about 0.3%. The ripening process of jackfruit is a complex mechanism, the final stages of which result in significant changes in taste, texture and color. Jackfruit is a climacteric fruit, clearly showing three stages of respiration, including pre-climacteric, climacteric and post climacteric [15]. Physiological, biochemical, and physical processes such as carotenoid biosynthesis, accumulation of sugar content, reduction of organic acid content, and changes in cell wall composition are obvious changes during the ripening process of jackfruit [16]. The main reserve substance in jackfruit is starch, which will be converted into sugar during ripening. This is characterized by a change in the color of the jackfruit bulb from light yellow to darker yellow along with the presence of a characteristic aroma. Mature jackfruit usually ripens after 3-4 days at the optimal temperature of 24-27°C. For large jackfruits, uneven ripening may occur. To overcome this problem, fruits can be treated with ethylene at a concentration of 50 ppm for 24 hours at 25°C [12]. Jackfruit is a type of fruit that has a sudden increase in the rate of ethylene biosynthesis and respiration when going through the ripening stage [17]. The results recorded the respiration rate of immature, mature and climacteric phase jackfruit as 160 mg CO<sub>2</sub>/kg/h, 20-25 mg CO<sub>2</sub>/kg/h and 250 mg CO<sub>2</sub>/kg/h, respectively. The climatic peak is shown three days after fruit ripening, then decreases to 60-70 mg CO<sub>2</sub>/kg/h after 8 days of ripening [18]. Wang *et al.* [17] also reported a sharp increase in ethylene yield three days after harvest and then a decrease. If the fruit is not used, after this period, fruit deterioration

begins. Besides, Morelos-Flores *et al.* [19] reported that the climacteric peak appeared differently among jackfruit varieties with different genotypes, with some varieties reaching the highest peak of 123.99 mL CO<sub>2</sub>.kg<sup>-1</sup>.h<sup>-1</sup> after 2 days of storage. The other cultivar reached the highest peak of 69.91 mL CO<sub>2</sub>.kg<sup>-1</sup>.h<sup>-1</sup> on the 4<sup>th</sup> day of storage and the remaining cultivar showed the highest peak on the 6<sup>th</sup> day of storage, with average respiration rate of 93.8 and 71.23 mL CO<sub>2</sub>.kg<sup>-1</sup>.h<sup>-1</sup>.

## 2.7 Storage

Due to the perishable nature of jackfruit, the quality and quantity always decrease significantly after harvest and in the supply chain. Cold storage is a popular and effective method to preserve fruits after harvest. In rural areas, unripe jackfruit can be helped to ripen by using a sharp stick to pierce the fruit's stem to the core. The fruit is then brought into the room, where the fruit is stacked with the punctured side facing up until optimal ripeness is achieved. The first report of cold storage of jackfruit (bulbs) was conducted by Singh and Mathur [20], indicating the maintenance of fruit sensory attributes. However, the study showed a decline in fruit pectin content and firmness due to activities of the pectin methyl esterase enzyme. After this, Latifah *et al.* [21] showed that storage at different temperatures affected the rate of respiration in minimally processed jackfruit. Accordingly, a sudden increase in respiration rate was noticed when fruit was stored at 10°C and 25°C on the second and fourth day of storage respectively, while the respiration rate remained low at 2°C for three weeks. Ying *et al.* [22] reported that combination dipping treatment of propiconazole at 250 ppm for 5 min and packing with perforated LDPE improve postharvest quality of jackfruit for 2 weeks at optimum storage temperature (12°C). Storage of whole jackfruit at 10°C and 85-90% humidity can extend the shelf life of the crop approximately by two weeks. Jackfruit harvested and stored at ambient temperature (28°C, RH 65-70%) can ripen 3 days later. Similar to climacteric fruits, if stored at 10°C (RH 85-90%), the shelf life of jackfruit can be extended to about 2 weeks [23]. The whole jackfruit harvested at 90-95 days, combined with dipping treatment of propiconazole at 250 ppm for 5 min, packing with perforated LDPE may improve postharvest quality of jackfruit for 2 weeks at storage temperature and relative humidity of 12°C and 85-90%, respectively [22]. Post-harvest jackfruit processing can be done for whole and cut jackfruit. Jackfruit is a climacteric fruit, the respiration rate (calculated according to CO<sub>2</sub> produced) at 5°C is 10-20 mg/kg/h [24]. Kader [25] determined the respiration rate of jackfruit at the pre-climacteric stage to be 20-25 mL CO<sub>2</sub>/kg/h and at the peak stage (climacteric) to be 50-55 mL CO<sub>2</sub>/kg/h when stored at 20°C. Fruit that reaches maturity can be stored for 4 to 5 days at a temperature of 23-35°C after harvest: or 2 to 6 weeks at 11-13°C with 85-95% relative humidity. At temperatures lower than 12°C, jackfruit exhibits symptoms of chilling injury including dark brown skin discoloration, brown pulp, deterioration of flavor and increased susceptibility to decay. Kader [25] also confirmed that the optimal temperature for jackfruit storage is 12-14°C with a post-harvest storage period of 2 to 4 weeks. The preservation process for exporting jackfruit in Vietnam has also been strictly implemented. After harvesting, there needs to be a way to preserve jackfruit in a dry, cool place, not placing it directly on the ground but

needing a tarpaulin/cover spread under it. Jackfruit can be stored for about 6 weeks at a temperature of 11-13°C. Storage warehouses need to meet conditions such as being dry, clean, airy, free of strange odors, free of toxic chemicals, and not stored with goods with strange flavors.

However, jackfruit is a tropical fruit, susceptible to cold damage at low temperatures, so this is also a big challenge and obstacle in applying this method to jackfruit to prolong its preservation time. Therefore, many other post-harvest management techniques have been conducted. Appropriate atmospheric modification packaging (MAP) can slow down the ripening and aging process, reduce the rate of respiration and ethylene synthesis, and slow down the change in structure (softer) and nutritional composition of the fruit [26]. Saxena *et al.* [18] reported a significant decrease in respiration rate, ethylene production and microbial activity in jackfruit pulp using the MAP method combined with pretreatment with sodium benzoate (0.045%), citric acid (1%), calcium chloride (1%) and ascorbic acid (0.02%). Then Saxena *et al.* [27] also reported that jackfruit that was minimally processed, applied MAP and stored at 6°C for 7 weeks had 31% higher content of vitamin C, carotenoids, flavonoids and total phenolics, respectively 43%, 8% and 7% compared to the control sample. The type of packaging used along with the gas composition can also be considered an important factor affecting fruit quality when preserved using the MAP method [23]. Thewes *et al.* [28] implemented a method of preserving jackfruit using controlled atmosphere methods. Preservation of jackfruit by controlled atmosphere storage method was also carried out by Anaya-Esparza *et al.* [29], who reported that the optimal gas composition was at a storage temperature of 5°C for seedless and seedless jackfruit. particles are 6-8% O<sub>2</sub> and 8-10% CO<sub>2</sub> and 4-7% O<sub>2</sub> and 10-12% CO<sub>2</sub>, respectively. Different sensitivities to CO<sub>2</sub> concentrations when they are too high or to O<sub>2</sub> levels that are too low also vary between fruit types, which may be due to differences in cultivar, structure and their metabolism (Thuy and Tuyen, 2016). Post-harvest treatment of fresh jackfruit with 1-MCP has also been done by some authors [30-32]. They reported that treatment of jackfruit with 1-MCP did not significantly affect jackfruit quality; however, it delayed ethylene biosynthesis, respiration rate, softened fruit flesh with an extended shelf-life of 12 days. 1-MCP was effective as a treatment on jackfruit in inhibiting ethylene production and reducing sugar content compared to the control sample. The accumulation of starch in young jackfruit gives the fruit greater firmness, while the onset of ripening activates sucrose-phosphate synthase (SPS), which in turn initiates the oxidation of starch to sucrose, a process was also reduced when 1-MCP was applied to jackfruit. Thus, applying 1-MCP slowed down the starch decomposition process, thereby delaying the activity of SPS compared to the control sample. 1-MCP also helped fresh jackfruit maintain firmness during the early stages of ripening but had no significant effect on fruit softening during later stages of ripening. Jackfruit segments treated with CaCl<sub>2</sub> at a concentration of 1% maintained better firmness, and the SSC and TA content were also higher after 13 days of storage compared to the control sample, as reported by Daryanti [33]. Jackfruit pulp was treated with CaCl<sub>2</sub> and citric acid, contained in polyethylene and polystyrene packaging as described by Sally *et al.* [34] demonstrated that it reduced bacterial penetration into jackfruit pulp during storage. Besides, Ramli and Ahmad [7]

studied and evaluated biochemical changes in the middle layer of fruit cell walls as storage time increased. They also showed that calcium treatment maintained the firmness of the fruit's flesh, which in turn also inhibited its biodegradation. Chulaki *et al.* [35] also demonstrated that the combined use of CaCl<sub>2</sub> and ascorbic acid maintained high levels of components such as reducing sugars, total soluble solids and acid in jackfruit pulp. The impact of UV-C treatment on reducing bacterial damage in jackfruit was evaluated by Bizura Hasida *et al.* [36]. They reported that jackfruit segments exposed to UV-C (240 nm) for 5 min and stored at 5°C resulted in superior quality and lower total microbial content and extended storage life of 14 day.

## 2.8 Market

Because jackfruits are heavy and bulky when transported and usually they are only harvested when fully mature and ripen about 3 to 5 years later. Therefore, jackfruit is often transported to nearby markets for fresh consumption. Processed products will be a more stable source for jackfruit to reach distant markets [37]. Vietnam's jackfruit export market potential is also very large, mainly to the Chinese market. The purchase rate of whole fruit only accounts for 3 to 5% of total consumption, the rest is mainly frozen jackfruit for export. Vietnamese jackfruit (frozen and processed) has also been exported to Australia in the past 2 years. In case the transportation distance to the place of consumption is too far, exported jackfruit needs to be stored in a cool warehouse with artificial refrigeration. Need to put into cold storage as soon as possible (calculated according to time after harvest). Jackfruit prepared for export is packed in cold containers at a temperature of 5 to 10°C, 50-60% humidity, and 25°C ventilation to ensure freshness when it reaches the recipient. The packaging process for jackfruit for export must also be done carefully to properly protect the product. Materials used for packaging must be clean and of good quality to minimize the risk of internal/external damage to the product. Materials and stamps related to commercial requirements must use printing ink and glue that are non-toxic to human health. However, it is easy to see that the edible part of the jackfruit only accounts for about 35% of the total weight. Therefore, transportation and packaging costs are very high, sometimes even difficult for whole fruits, which also creates barriers for selling unprocessed fruits in the domestic market. Value-added products such as vacuum fried jackfruit, dried jackfruit... created will be more commercially suitable, increasing the efficiency of use and economic value of this fruit. In addition, taking advantage of valuable by-products from jackfruit to create products with commercial value is also a development direction in Vietnam today.

## 3. Chemical composition and nutritional value

Ripe jackfruit is eaten fresh or used to make fruit salad with high nutritional value. Jackfruit is rich in fiber, so it is also a good source of laxative. The fiber content helps protect the colon mucous membrane by reducing exposure time and also binding to cancer-causing chemicals in the colon. Fresh jackfruit contains small amounts of vitamin A and flavonoid pigments such as β-carotene, xanthin, lutein and cryptoxanthin. Together, these compounds play important roles in antioxidant function and human vision [38]. Fresh jackfruit contains high water and carbohydrate content, 72.0-77.2% and 18.9-25.4% respectively. Jackfruit

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also contains other vitamins besides vitamin A, such as B1, B2, B3 and C along with minerals (calcium, phosphorus, iron, sodium, potassium) [8]. Both young and ripe jackfruit contain the nutritional ingredients mentioned above. However, young fruits contain higher levels of protein, fiber and vitamin C than ripe jackfruit, while other contents such as total sugar and vitamin A are lower. The remaining ingredients are almost equivalent between young jackfruit and ripe jackfruit [39]. Jackfruit seeds contain large amounts of protein and carbohydrates, 6.6% and 38.4% respectively, higher than jackfruit segments (protein only from 0.3 to 1.9%), along with important minerals such as calcium, phosphorus and iron [8].

## 4. Uses and processing

### 4.1 Ripe Jackfruit pulp

Ripe Jackfruit pulp can be eaten fresh and have a very sweet taste due to their high sugar content such as glucose and fructose (10-15%). In different regions of Vietnam, jackfruit is used differently. In Hue of Vietnam, Jackfruit is mixed with shrimp, onions, and fish sauce and served with grilled rice paper. Young Jackfruit can be used as a vegetable to cook soup, braise with fish, stir-fry with meat, and make salad. Jackfruit fiber can be used to make pickles. This dish is made from ripe jackfruit fiber or from green jackfruit. Jackfruit is also processed into many other value-added products such as green jackfruit pickle, jackfruit rind jelly, Jackfruit bulb jelly and jam, jackfruit squash, jackfruit sweet pickle [38]. The effect of CaCl<sub>2</sub>, ascorbic acid, citric acid and sodium benzoate pretreatments followed by chitosan coating on fresh-cut jackfruit bulbs was conducted by Saxena *et al.* [40]. Sample were treated differently and preserved using controlled atmosphere (CA) methods. The research results have shown that combining CA conditions (3 kPa O<sub>2</sub> + 6 kPa CO<sub>2</sub>), pretreatment and chitosan coating significantly reduced the loss of total phenolic and ascorbic acid content, limiting microorganisms invade and prolong the preservation period to 50 days. Jackfruit is also processed into many different forms such as jam and jelly. The effect of a combination of treatments on the quality of fresh cut jackfruit segments was also conducted by Prathibha *et al.* [41], the results showed that pretreatment of raw materials with 0.5 to 1% CaCl<sub>2</sub> combined with 0.25% ascorbic acid has maintained the quality of cut jackfruit segments well and also extended the product shelf life up to 3 weeks.

### 4.2 Utilization of jackfruit by-products

Jackfruit by-products also contain nutritional ingredients and biologically active compounds, so they can bring many potential applications in product processing and trading activities. This activity also supports and directs the development of a circular economy, associated with the goals of environmental protection and sustainable development in many fields in Vietnam. Extraction processes or processing of by-products are promising sources of valuable substances such as vitamins, phytonutrients (carotenoids, phenolics and flavonoids), antioxidants, antimicrobials, lipids [42, 43]. These ingredients assist in enhancing the nutritional value of food products. Ajey [44] studied on jackfruit waste for the nutrient-enriched animal feed by supplementing nitrogen and fermenting with yeast (*S. boulardii*) and LAB (*L. acidophilus*).

#### 4.2.1 Jackfruit seeds

Jackfruit seeds are also edible and have certain nutritional value. The seeds can be roasted, boiled, or steamed or braised with fish. Before eating, peel off the thin outer shell; has an aromatic and nutty taste. The physicochemical properties of jackfruit seed starch were studied by Wong *et al.* [45] and compared with rice starch and potato starch. The amylose content of jackfruit seed starch is 25%, similar to potato starch (27%) but higher than rice starch (17%). Jackfruit seeds can be pre-processed with salt water to remove slime, then dried, peeled, boiled, then ground finely like green bean flour and used in making folk cakes such as sticky rice cakes and pies.

#### 4.2.2 Leaves

According to traditional medicine, the entire jackfruit tree is used to treat diseases. Acrid green fruit tones the skin. Ripe fruit with jackfruit segments has a sweet taste, warm properties, and has the effect of quenching thirst, supporting the lungs, and eliminating negative heat. Jackfruit seeds have a sweet taste, neutral properties, fragrant aroma, and have the effect of cultivating beneficial energy and promoting milk production. Jackfruit leaves also have good health effects. In Vietnam, people often use jackfruit leaves in combination with sugarcane leaves and bamboo charcoal in equal amounts to make a decoction to treat asthma; With multiflora root, plantain, grass root, cat's whiskers or corn silk (equal amounts), decoct and drink to treat kidney stones. Jackfruit leaves can also be used as a folk remedy to reduce swelling and pain. Young jackfruit is peeled, sliced, stir-fried with lean pork, seasoned with spices, and eaten with rice. The remedy has the effect of strengthening the spleen, harmonizing the liver, increasing and releasing milk, suitable for postpartum women who are weak, have poor appetite, and have little milk. Jackfruit leaves also cure indigestion, digestive disorders caused by eating cold raw foods, support the treatment of hypertension...

#### 4.2.3 Peel

The outer layer of jackfruit consists of a peel with thorns on the surface. Jackfruit peels are considered inedible and are usually thrown away. However, recently this part has also been used as a source of fertilizer for plants. Jiang *et al.* [46] showed that the peel is also a source of total phenolic content (8.14 mg GAE/g DW) with antioxidant activity, so this can also be a potential source for the industry. food and pharmaceutical industry. Jackfruit seed powder has also demonstrated antibacterial properties [47]. Jackfruit peel has more phenolic content than jackfruit pulp, so it has good potential to be developed as a natural antioxidant or further used to prepare functional foods [48]. Cellulose nanocrystals extracted from jackfruit peel have several applications in the food sector [49]. Thomas and Dharmapalan [50] studied including green Jackfruit powder in the diet of patients undergoing chemotherapy to prevent chemotherapy-induced leukopenia.

### 5. Proposing a circulatory model for jackfruit trees in Hau Giang

From the process of producing jackfruit trees in large quantities in Hau Giang province, Vietnam today, post-harvest products and by-products will be available in large quantities. Resources include jackfruit fruit, leaves, tree

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trunks, young fallen fruit. With jackfruit that meets quality and quantity standards, it can be sold to traders at a high purchase price. Fruits that are small in weight, substandard, have defects, etc.. will be used for convenient product processing such as minimally processed fresh jackfruit products, dried jackfruit, vacuum-fried jackfruit, jackfruit wine, jackfruit jam/jelly, drinks, jackfruit candy... or added to ice cream. Jackfruit seeds can be used to recover powder, used in the preparation of baked goods, bread, noodle/noodle products... Seed powder can also be used in the preparation of plant milk with high content of nutrients. The fruit peel contains high levels of biologically active compounds, so this is also a potential source for extracting phenolic compounds, which are natural antioxidants or further used to prepare functional foods. The fruit peel will be used together with jackfruit leaves and black jackfruit as well as young fallen fruit to feed the goat raising process. The raised goats will be sold as meat goats or breeding goats, and the goat manure during the captive process will be used as fertilizer and back to the plants. Jackfruit tree trunks can be used to make wooden statues or musical instruments. Young jackfruit can be processed into fermented products, making products similar to meat. The proposed models can be suitable for local conditions, taking advantage of agricultural by-products, especially jackfruit, to increase farmers' income. In addition, livestock farming using natural feed is also developed, creating products from clean and safe plants and animals. Thus, it is possible to reuse waste resources from jackfruit grown in domestic regions, bringing them back into the economy instead of throwing them away. Although achieving all of these proposals requires great efforts from individuals, businesses and governments. However, the success they bring to a region or country will be realized with great benefits such as reducing the use of non-renewable resources, reducing carbon emissions, zero waste goals, bringing benefits to consumers and opening up new opportunities for domestic companies to develop more stably, sustainably and earn higher profits.

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