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A REVIEW ON DEVELOPMENT OF DIFFERENT VALUE-ADDED PRODUCTS FROM EDIBLE AND NON-EDIBLE PARTS OF DRAGON FRUIT (*Hylocereus* sp.): OPPORTUNITIES AND CONSTRAINTS

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ABSTRACT

Dragon fruit (*Hylocereus spp.*), commonly known as pitaya or pitahaya, is an emerging exotic fruit with vibrant colouration, appealing sensory attributes and promising nutritional and bioactive properties. Both the edible pulp and non-edible fractions (peel, seeds, flowers and stems) present opportunities for diversified product development. This review synthesizes recent advances in processing, product formulation and waste valorisation of dragon fruit, covering dehydrated snacks, juices and fermented beverages, jams and confectioneries, bakery applications, spray-dried powders, natural colourants, nutraceutical extracts and bioplastic/cosmetic applications from peel and other by-products. The review highlights processing techniques that improve retention of betalains and phenolics (freeze-drying, microwave-vacuum, ultrasound-assisted extraction), approaches for seed oil and protein recovery, and fermentation strategies to enhance functional properties. Key constraints including disease pressures, short postharvest shelf life, processing costs and regulatory concerns for food ingredients are discussed alongside economic considerations for smallholders. Research gaps are identified in standardisation of extraction methods, shelf-stable product formulation, life-cycle assessments for bioplastics, and pilot-scale upscaling. Strategic integration of circular-economy principles, value chain strengthening and targeted R&D could position dragon fruit as a sustainable platform crop for food, nutraceutical and industrial markets.

***Keywords* :** Dragon fruit; *Hylocereus*; value addition; betalains; waste valorisation.

Introduction

Dragon fruit (*Hylocereus* spp.) has varied benefits and uses, and both the edible and non-edible parts can be efficiently utilized in product development and value addition, as every part has tremendous nutritional values and fibre content. Studies have shown that dragon fruit is composed of 25-40% non-renewable shell, 45-70% pulp and 8-15% seeds (*Nizamlioglu et al.,* 2021). The pulp being the main component of the fruit is eaten raw and noted to have high antioxidant values and can be consumed in varied forms, as juice, dessert, jelly, wine etc. The peel is not only a good source of betacyanin with potential as a natural colourant but it is known to have antibacterial value and a source of pectin. Seeds are easily digestible and are rich in lipids, potassium, magnesium etc. Young stems, flower buds and flowers are also consumed as vegetables, which are steamed or steeped as tea (Nangare *et al.,* 2020). Not only in culinary field but dragon fruit utilization holds immense scope in the field of nutraceuticals, medicines, cosmetics, animal fodder etc. Also, being a seasonal fruit and highly perishable in nature, processing into value-added products is advisable to enjoy the benefits of the fruit throughout the year.

Dragon fruit presents significant opportunities for value addition through processing of both edible and non-edible parts into nutritionally rich products while addressing waste management challenges. The fruit's bioactive compounds offer health benefits including blood sugar reduction, cholesterol management, and cancer prevention (Tarte *et al.*, 2023). Specific value-added products have been successfully developed, such as dragon fruit jelly enhanced with cardamom, which demonstrated optimal quality parameters and a benefit-cost ratio of 2.33 (Narayan & Prasad, 2023). Processing technologies enable utilization of dragon fruit pulp, peel, and seeds, contributing to waste reduction and creating opportunities for food and industrial applications (Jalgaonkar *et al.,* 2020). Advanced valorisation approaches include microbe-based conversion of dragon fruit waste into bioethanol, bioactive products, and pharmaceuticals, supporting circular economy principles and generating valuable bioproducts for energy, food, and pharmaceutical sectors (Tripathi *et al.,* 2024). These advancements highlight the dragon fruit's potential as a versatile resource for creating a diverse range of products that cater to health, environmental sustainability, and commercial needs. The development of value-added products from dragon fruit emphasizes a comprehensive utilization approach that enhances economic value, reduces environmental impact, and maximizes health benefits. As consumer interest in exotic and nutritious foods continues to grow, processing industry using dragon fruit is likely to see further expansion and diversification.

The central and southern provinces of Vietnam are home to a large population of dragon fruit (*Hylocereus* spp.). Dragon fruit has several applications in the food, medicinal, and cosmetic industries in addition to its great economic worth. In several Western and European nations, this cactus species is also used to make pickled cactus, cactus juice, cactus cocktails, etc. (Piga, 2004 and Feugang, 2006). Only the fruit's edible pulp, which has a high export value, makes it viable in Vietnam; the remaining fruit parts, including as the skin, stem, and flower remains, are discarded as agricultural waste, which has a negative impact on the environment. Fruit skin, stem, and blossom remains have been utilized for medicinal purposes, including the removal of toxins, the treatment of fire burns, the healing of fractured bones, the application of food colouring, and the production of antioxidants (Piga, 2004). The objective of this review is to investigate the different kinds of products from edible and non-edible parts of dragon fruit, such as wine, RTS, food pigment, jam, soft drink, tea etc.

Very little research has been done on this fruit crop in India. The dragon fruit is a super fruit that was recently introduced to the country and is thought to be a promising and rewarding fruit crop. It has a very attractive colour and a fluffy pulp with a black edible seed embedded in the pulp with huge nutrient properties. The fruit has a fairly low calorie content and contains small amounts of multiple nutrients, including iron, magnesium, and fiber (Kakade *et al.,* 2022).

Nutritional and Bioactive Composition

Dragon fruit pulp is predominantly water (85–88 g/100 g), contains low fat (0.3–0.6 g), modest protein (1.0–1.5 g) and dietary fibre (2.5–4.0 g) and is a source of vitamin C, B-complex vitamins, essential minerals (Fe, Ca, P, K) and bioactive pigments such as betalains (betacyanins and betaxanthins) (Ibrahim *et al.,* 2018). Betacyanins impart the characteristic red to magenta colour in red-fleshed cultivars and show antioxidant activity. The peel fraction contains higher concentrations of phenolics, dietary fibre and pectin which are useful for food texture modification and as a source of natural dyes.

Table 1: Nutritional Values per 100 g of dragon fruit.

Nutrient	Amount (per 100 g)	Remarks
Water	87 g	Primary constituent
Energy	50–60 kcal	Low calorie
Protein	1.1 g	Low
Fat	0.4 g	Low
Carbohydrates	11 g	Includes sugars
Dietary fibre	3.0 g	Prebiotic potential
Vitamin C	20 mg	Antioxidant
Iron	1.9 mg	Notable for fruit
Betalains (red cultivars)	Variable (µg–mg/g)	Natural colourant, antioxidant

Source: ICAR technical bulletin-47 (Nangare *et al.,* 2020).

Global Production, Cultivation and Market Potential

Production of dragon fruit worldwide, it was first grown commercially in tropical South Asian nations in 1990, including southern Mexico, Guatemala, and Costa Rica. Many nations, including Vietnam, China, Mexico, Colombia, Nicaragua, Ecuador, Thailand, Malaysia, Indonesia, Australia, and the United States, are currently seeing substantial fruit production and expansion. However, aside from its impromptu global expansion, its manufacturing and marketing data are rarely accessible. Depending on market availability, productivity, planted regions, and economic considerations, dragon fruit is categorized as a minor tropical fruit (Abdulshahed *et al.,* 2020). Evidence from specific nations as well as recent studies from a few private organizations indicate that dragon fruit production has expanded dramatically in the past and current decade (Rashidian *et al.,* 2020). More than 93 percent of the dragon fruit produced worldwide comes from three big nations: China, Indonesia, and Vietnam. Vietnam alone accounts for more than half (51.1%) of global output, covering 55,419 hectares with an average productivity of 22–35 metric tonnes (MT)/hector (ha) annually. Vietnam produces around a million metric tons of dragon fruit annually (Wakchaure *et al.,* 2020). Dragon fruit's potential worldwide market are:

A) Asian market as the greatest number of dragon fruit users are in Asia, especially among Chinese people, who believe that the fruit's name, shapes and colours bring good fortune. The fire religion is the main reason why Asian consumers, especially those in China, purchase dragon fruits. They frequently focus on the shape of the dragon's fruit. The Japanese, however, prefer the taste of the dragon's large fruit over its size, thus they dislike it.

B) The European market is highly receptive to new items and is the world's biggest importer of fresh produce. Consequently, although being relatively new and not well-known, the dragon fruit is still highly promising and drawing more and more customers to the continent despite its high price. The fruits of the dragon will undoubtedly be available to the vast majority of people in European nations because to their decreased cost and increased nutritional content.

C) The US market: Asian consumers in the US have historically enjoyed dragon fruit. Due to the substantial Asian and Vietnamese population, the demand for dragon fruit is relatively high. Although the dragon fruit is relatively new to other ethnic groups and only known in the premium market segment, analysts argue that this is a growing market in the near future as farm owners in Florida and California have begun planting dragon fruit to meet market demand (Paull and Chen, 2019).

About 70% of India's dragon fruit production comes from the water-scarce areas of Gujarat, Northern Karnataka, and Western Maharashtra. Overall, southern and western states are contributing a major share to the production of dragon fruit since they have been growing it for the past five to eight years. For instance, after witnessing the fruit's performance, over 600 farmers in Karnataka alone have begun growing dragon fruit in the past five years. In Karnataka, the area used for dragon fruit farming increased from 8–10 hectares in 2012 to 500 hectares in 2020, and it is anticipated to reach 5000 hectares in the following five years. This fruit is being grown on about 800 hectares of land by more than 200 farmers in Gujarat's Kutch region (Wakchaure *et al.,* 2020).

Utilization of Edible and Non-Edible Parts

Some of the studies on utilization of dragon fruit have explored these possibilities:

Processing and Waste Utilization: Dragon fruit is processed into various value-added products. The pulp, being rich in nutrients, is often used to make juices, jams, and jellies. Additionally, using by-products like peels and seeds helps reduce waste and adds value. For example, peels can be used to extract pectin, which is beneficial for food and industrial applications (Jalgaonkar *et al.,* 2020). The transformation of these materials into valuable components is highlighted as an important environmental concern and an innovative way to manage food waste (Taharuddin *et al.,* 2023).

Bioactive Compounds and Nutritional Benefits: The fruit is known for its bioactive potential, offering medicinal benefits such as reducing blood sugar levels and cholesterol. The processing of both edible and non-edible parts helps in preparing nutritionally rich products, thus addressing waste generation challenges (Tarte *et al.,* 2023). The peel, rich in phytochemicals and antioxidants, can be repurposed in the food and pharmaceutical industries, contributing to health benefits like anti-cancer and anti-diabetic effects (Jimenez-Garcia *et al.,* 2022).

Sustainable Development and Applications: In Vietnam, dragon fruit has become a vital crop due to its nutritional properties and adaptability to different environmental conditions. This adaptability aids in the sustainable development of local economies while addressing the impacts of climate change (Luu *et al.,* 2021). Dragon fruit peel, rich in lignocellulosic biomass, has been identified as a promising source for bioplastics. The bioplastic industry benefits from using dragon fruit waste to create materials that are biodegradable and environmentally friendly, reducing the reliance on petroleum-based plastics. This application is particularly relevant in consumer goods packages, agricultural films, and disposable items, which typically contribute to environmental pollution when made from conventional plastics (*Taharuddin et al.,* 2023).

Natural Dyes: Dragon fruit, known for its vibrant color due to the presence betacyanin pigment, is an excellent source of natural dyes. These can be used extensively in the textile industry for dyeing fabrics. The environmental benefits of using dragon fruit-derived dyes include reduced pollution from toxic synthetic dyes and aligning with increasing consumer demand for sustainable and eco-friendly products. Moreover, the natural dyes extracted (Figure 1) from dragon fruit have been shown to enhance the antimicrobial properties of fabrics, adding functional value to the textiles beyond coloration (Sadannavar *et al.,* 2024).

Metabolic and Nutritional Variations: Different cultivars of dragon fruit have been analyzed for their nutritional content, showing variations in protein, fiber, antioxidants, and minerals among different species. These findings can guide dietary planning and functional food development (Yasmin *et al.,* 2024). Additionally, metabolomic studies highlight altitudinal influences on the nutritional profiles of dragon fruit, offering insights into optimal cultivation practices for enhancing the nutritional quality of the fruit (Zhao *et al.,* 2024).

Value-added product categorizes and Processing Technologies

A detailed speculation on the varied products of dragon fruit processed by researchers are discussed as follows (Table 5)

Dehydrated products (slices/ chips)

Chips in varied forms are a great choice of snacks which are tasty, versatile and liked by all. Dragon fruit chips are rarely available in market, though there is immense scope for its own niche, as dehydrated dragon fruit chips can be a delicious low-calorie snack with its attractive colour and high nutritious content. Puspitojati *et al.* (2023) studied the quality of tortilla chips modified with red dragon fruit peels and was found to exhibit higher antioxidant activities and organoleptically favored. Dragon fruit slices with peel of 1 cm thickness were freeze dried and rehydration aspects were studied, which showed freeze drying is suitable for industrial production as a value added product (Mawilai *et al.,* 2017). Furthermore, researchers have tried a wide range of drying technologies for dragon-fruit chips: microwave-vacuum (Raj and Dash, 2020), intermittent microwave-convective drying (Raj and Dash, 2022), vacuum drying, hot-air, freeze-drying, refractance-window (Dadhaneeya *et al.,* 2023) and combined or assisted methods (ultrasound + osmotic, blanching pretreatments) (Pham *et al.*, 2024).

Table 2: Different approaches for dehydrated chips from dragon fruit.

Authors (Year)	Fruit Type	Drying Method	Pretreatment	Key Findings
Darshan *et al.* (2025); Dadhaneeya *et al.* (2023)	White-fleshed pitaya	Hot-air, Freeze-drying, Refractance window drying (comparison)	None	Freeze-drying retained highest phenolics & antioxidant activity; RWD balanced quality & speed; hot-air caused more pigment loss
Khatun *et al.* (2024)	Red pitaya	Microwave-vacuum drying (MV)	None	MV reduced drying time, better texture & color retention vs. hot air; provided drying kinetics models
Raj and Dash (2022) Pham *et al.* (2024)	Red pitaya	Ultrasound-assisted osmotic dehydration	Ultrasound + osmotic solution	Ultrasound + osmotic pretreatment improved water removal, reduced drying time, better color retention
Banh *et al.* (2022)	Red pitaya	Vacuum drying (Taguchi optimization)	Blanching, slice thickness variation	Vacuum drying optimized for crispness & color using Taguchi; identified key parameters (temp, time, vacuum level)
Raj and Dash (2022)	Red pitaya	Intermittent microwave-convective drying (IMCD)	None	IMCD improved phenolic retention & reduced color change vs. convective drying; good rehydration ratio

Juice, Beverages and Fermented Drinks

Fruit juice and its processed products are one of the most popular fruit products in markets with nutritional benefits, detoxifying attributes and a favorite of all age groups. Dragon fruit known for its health benefits and vivid color is a great choice for preparing diversified beverages which are equally agreeable to both health savvy and general consumers. Blended fruit beverages are a boon economically and nutritionally, whereby it was found that pure dragon fruit beverage had highest antioxidant activity while maximum β-carotene content was recorded in dragon fruit: watermelon blended beverage (Pavithra and Mini, 2023), dragon fruit with 3% lime juice and 500 ppm ascorbic acid had better retention of betacyanin (Patel and Bishe, 2024). Jalgaonkar *et al.* (2018)

recommended a micronutrient-enriched dragon fruit based health drink with 70% dragon fruit juice, 5% grape juice, 3% sugar syrup and 22% pomegranate juice, while solely dragon fruit based RTS beverage with 12 per cent juice, 0.4 per cent citric acid, 12 per cent sugar and 0.01 per cent KMS preservative was found best by Foke *et al.* (2018).

Dam (2013) developed five products from different parts of dragon fruit *viz*., wine from fruit pulp, betacyanin extract and jam from fruit peel, soft drink from plant stems, and tea from flowers. Minh *et al.* (2019) on dragon fruit nectar concluded that dragon fruit nectar had the best quality by adjusting at pH 4.2, sugar supplementation 8%, pasteurized at 95ºC for 1 minute, cooled and stored at 4 ± 2 ºC in glass bottle for 3 months. One of the diversified product of dragon fruit juice is a low-calorie probiotic drink, prepared using *Lactobacillus paracasei* ssp. *paracasei* Ml.3 (Augustina *et al.,* 2023), as fermented fruit juice have longer shelf life and resistance to food-borne microbial spoilage which reduces dependency on synthetic preservatives. Muhialdin *et al.* (2020) demonstrated the high potential for lacto-fermented dragon fruit juice for applications to improve the functional properties, consumer acceptability and shelf life of fresh dragon fruit juice. Additionally, fermentation technique was adopted to improve the yield of betalains present in fermented dragon fruit drink, which indicated nine-fold more concentration of betalain than the non-optimized fermentation (Choo *et al.,* 2018), posing as a potential economic processing technique to concentrate bioactive compounds present in functional drinks.

Nguyen (2020) studied on the utilization of acoustic treatment or ultrasound processing on dragon fruit mash to produce beverage and found it to be a viable alternative method in extraction of antioxidant rich juices. A diabetic friendly jelly drink was formulated using dragon fruit juice, jamblang leaf extract, carrageenan, and stevia, which aims to reduce sugar intake and increase antioxidant supply and the formulation of dragon fruit juice extract and jamblang leaf extract of 80:20 and 0.3% stevia and 0.3% carrageenan concentrations was found to be best (Sulaswatty *et al.,* 2024). Hanafi *et al.* (2023) purposed to formulate the considered waste- dragon fruit peel extract and catfish bone gelatin into a functional drink.

Lim *et al.* (2024) evaluated the potential of a functional fruit drink, Fermented Red Dragon Fruit Drink (Improved-FRDFD-dH_2O) containing betacyanin of fermented red dragon fruit drink stabilised by 0.4 % xanthan gum and 0.5 % carboxymethyl cellulose hydrocolloid mixture solution and 0.2 % citric acid which proved as a sustainable functional colourant with antioxidant properties for producing beneficial yoghurt.

Jam, Jelly and Confectioneries

Table 3: Different works accomplished on confectionary products from dragon fruit.

Authors (Year)	Product Type & Focus	Methods	Key Findings
Archana *et al.* (2023)	Jam, Jelly, jujube, squash, RTS, cookies & ice-cream	Sensory & physicochemical evaluation	Dragon fruit jam scored higher sensory rating.
Castro *et al.* (2021)	Jam with pulp + peel	Sensorial, biochemical, microbiological	Peel improved antioxidants, B complex vitamins, and consumer acceptance
Lestari *et al.* (2023)	Jam with pulp + peel	Organoleptic, TPC, microbial counts	High color acceptance, safe microbes, peel enhanced fibre content
Thakarya *et al.* (2025)	Dragon fruit–guava blended jam	Storage study (6 months)	100% DF jam highest anthocyanin & antioxidant; acidity increased, vit C decreased
Das *et al.* (2024)	DF jam with leaf extracts (tulsi, lemongrass & mint) & alternate sweeteners (honey, stevia & coconut sugar)	Physicochemical study (14–28 days)	Mint + stevia best; pH ~4.1; vit C ~9 mg/100 g; good texture
Nisa *et al.* (2018)	Jam from peel + flesh (ratios)	Organoleptic, proximate, antioxidant, viscosity	70 g peel + 30 g flesh best; high antioxidant & viscosity

Kumar *et al.* (2025)	Jam, jelly, RTS with pulp with natural sweeteners (sugar, honey & stevia)	Physicochemical, microbiological, sensory	Stable 6 months; honey smoothened texture
Magallanes *et al.* (2021)	Jam with dragon fruit peel + passion fruit juice	Response surface regression, sensory	Best: 50:50 DF peel with fruit bits + 15% passion fruit juice; score 8.35/9
Nizori & Lamtiar (2020)	Pedada jam fortified with DF peel extract	Physicochemical	Peel improved anthocyanin, antioxidant, color stability
Islam *et al.* (2012)	Jelly from pulp	Pectin levels (0.05–1.5%), storage 6 months, sensory evaluation	1.5% pectin best; stable 4 months
Panchal (2018)	Jelly from pulp	Standardized sugar/pectin levels; sensory	Best recipe by panel; proximate data
Narayan & Prasad (2023)	Value-added jelly	Recipe optimization	Optimized formulation developed
Baihaqi *et al.* (2023)	Jelly candy (dragon fruit pulp + rambutan fruit)	Different pulp ratios; sensory, chemical	70% dragon fruit + 30% rambutan best
Shendge *et al.* (2024)	Jelly candy with jaggery powder	Sugar vs jaggery ratios; proximate, sensory	30 g jaggery best, score 8.6/9
Nurhafsah *et al.* (2023)	Jelly candy with peel + pulp	Varied peel/pulp; chemical & sensory	150 g peel + 60 g pulp best; high acceptance
Soedirga & Marchellin (2022)	Jelly candy (peel pectin + carrageenan)	Ratios of peel pectin & carrageenan; texture	4.5% concentration and 2:1 ratio best
Assa *et al.* (2022)	Jelly candy from peel + tomato juice	Peel/tomato ratios; phenols, antioxidant	Peel-only highest phenols & vitamin C
Lestari (2016)	Jelly using peel extract	Betacyanin extraction (pH, solvents); organoleptic	pH 4.5 best; stable color, good acceptance
Sulaswatty *et al.* (2024)	Jelly drink (Dragon fruit + Jamblang leaves)	Juice + jamblang ratios, stevia	80:20 ratio best; high antioxidant, low calorie

Bakery and Cereal Products

The incorporation of dragon fruit and its by-products into baked products has received growing attention, both for their nutritional contributions and their potential to enhance visual appeal. Dragon fruit flesh, peel, and pigments have been evaluated in bread, buns, cookies, donuts, and cakes, either as direct ingredients or functional fortifiers, which are means of waste utilization (Cáceres *et al.,* 2023). Jati *et al.,* (2024) found that adding red dragon fruit puree (10–60%) to white bread, steamed buns, and donuts increased moisture and dietary fiber while boosting phenolic content and antioxidant activity. Sensory evaluations found that baked items with 40–60% puree scored higher in color and taste than control versions. The use of dragon fruit peel powder in raw cookie dough increased their bioactive and antioxidant capacity (Chumroenvidhayakul *et al.,* 2023). Yen *et al.*, (2022) successfully optimized passion fruit and pectin in red dragon fruit bar with optimal concentrations of 29.64% passion fruit and 1.35% pectin.

Dried Powder, Natural Colourants and Extracts (Table 6)

Dried dragon fruit powder is a novel product used as a natural colorant and health supplement. The powder retains the vibrant colour and nutrient profile of the fruit, making it suitable for use in food products (Tze *et al.,* 2012 and Homthawornchoo *et al.,* 2023).

Bioplastics and Cosmetics:

The peel, rich in lignocellulosic biomass, is being developed for use in bioplastics and natural dyes. These sustainable alternatives contribute to reducing environmental pollution and are applied in packaging and consumer goods (Taharuddin *et al.,* 2023 and Agung *et al.,* 2024).

Nutraceutical Products:

The fruit is also used to extract bioactive compounds that are incorporated into nutraceuticals. These products exploit the fruit's health benefits, such as reducing blood sugar levels and cholesterol (Nishikito *et al.,* 2023).

Functional Foods and Additives:

Dragon fruit is utilized for its functional properties in food fortification. Its extracts are added to foods to enhance nutritional value and impart health benefits, thus providing a dual benefit of flavor and functionality (Taharuddin *et al.,* 2023).

Processing, Stabilisation and Quality Considerations

Retention of sensitive bioactives (betalains, vitamin C, phenolics) is dependent on gentle processing: low-temperature drying, short thermal treatments, use of antioxidants (ascorbic acid) and pH control. Packaging (oxygen barrier, light protection) and inclusion of natural stabilizers increase shelf life. Microbial safety, water activity control and standardised preservation methods are essential for commercial acceptance.

Challenges and Constraints

Dragon fruit has many health benefits, but collecting high-quality fruits is always difficult because of a variety of infectious diseases (bacterial, viral, fungal, and nematode diseases) that can negatively impact plant growth. Anthracnose is the most harmful and commonly reported fungal disease among the 21 species of fungi that are known to cause different diseases in dragon fruit. Several species of *Colletotrichum*, including *C. gloeosporioides, C. karstii, C. aenigma, C. truncatum,* and *C. siamense*, are responsible for this disease (Kee *et al.,* 2019, Zakaria, 2022). A novel fungal disease that damages fruit is linked to the development of reddish-brown patches that are produced by *Nigrospora sphaerica*. Additionally, *Enterobacter cloacae* causes soft rot, one of the two bacterial illnesses. Some symptoms of infected pitaya in Korea, the United States, China, Japan, Taiwan, and Malaysia are also known to be caused by the cactus virus X (Balendres and Bengoa, 2019). Furthermore, difficulties that arise after harvesting are also troublesome. Dragon fruit is not a climacteric fruit, and while it is at its best when picked ripe, its flavor deteriorates while it is being stored. Water loss, mechanical damage, and chilling harm are the post-harvest issues with dragon fruit. When the scales darken, the outer layer of the flesh turns brown, the fruit becomes translucent, and the fruit shrivels, it is indicative of chilling injury. Chilling damage can happen at temperatures between 5 and 10 ºC. additionally, it is influenced by the ripening stage, genetic background, and growth environment. Harvesting the fruit at the right ripening stages and taking care during the post-harvest period can help prevent mechanical injury, which is typically caused by significant water loss that results in the creation of sunken areas in the fruit. Another significant issue with dragon fruit is the formation of wrinkles on its surface, which typically shortens its shelf life, detracts from its aesthetic appeal, and reduces its marketability. According to Freitas *et al.* (2013), using perforated bags can reduce the amount of water that the fruit loses. After being harvested for this investigation, the fruits were wrapped in tissue paper. Additionally, fruits were divided into three groups and kept in storage at 5, 7, and 10 °C with and without plastic bags for 20 days. After that, the shelf-life conditions were kept at 20 °C for five days. In comparison to fruits stored at 10 ºC, it was observed that fruits stored at 5 ◦C and 7 ◦C had superior visual quality. The fruit in the group that was kept at 10 °C without a plastic bag lost more weight during storage. Perforated plastic bags can help reduce fruit weight loss, but they also raise the chance of decay. In one study, fruits that were stored in a bag at 5 °C exhibited 10% decay while the one without the bag had no decay. Perforated plastic bags can help reduce fruit weight loss, according to the results, but they should be used in conjunction with a decay management technique (Freitas *et al.,* 2013). Wang *et al.* (2024), Som *et al.* (2019) noted in their studies that dragon fruit is prone to quick senescence, wilting, degradation, and water loss. Thus, the fruit's quality could be preserved by chemical treatment, heat shock, bagging, and cold temperature storage. The senescence of dragon fruit was postponed in this work by using benzo (1,2,3)-thiadiazole-7-carbothioic acid S-methyl ester (BTH), and the water loss was postponed. The phenylpropanoid pathway and an increase in antioxidant activity were credited with postponing senescence. Additionally, BTH therapy was found to have improved the phenylalanine ammonia-lyase (PAL), cinnamate-4-hydroxylase (4CL) and cinnamate-4-hydroxylase (C4H) activities which had led to increase in phenols, lignin and flavonoid production (Luu *et al.,* 2021).

Economic and Value Chain Considerations

Estimated establishment costs for a commercial dragon fruit orchard may range from Rs. 9–10 lakhs per hectare (Nangare *et al.,* 2020), including planting material, support systems and irrigation. Value addition by producing processed goods (RTS, powders, jams) increases farm-gate income by capturing processing margins. Cooperative models and micro-enterprises can reduce capital burden while aggregating produce for processing (Shete *et al.*, 2025).

Table 4: Estimate on establishing dragon fruit plantation.

Sl No.	Cost of cultivation	Cost description/ha	Amount (Rs.)
1.	Planting materials	4,000 cuttings 4 plants/pole structure Rs. 30 per plant or cutting	1,20,000
2.	Land/rental value of farm	Rs. 30,000 per annum/ha	30,000
3.	Drip irrigation system	Rs. 60,000/- for one ha	60,000
4.	Cost of support systems	1,000 support poles/ha	5,00,000
5.	Labour cost in Dragon fruit farm	625 man days per annum including family labour Rs. 5,000 per month 60,000 for on skilled labour	2,26,000
6.	Manures, fertilizers and nutrients	Rs. 55,000 in a year	55,000
7.	Pesticide	Rs. 20,000 in a year	20,000
8.	Intercultural operations	Rs. 12,800 in a year	12,800
9.	Miscellaneous costs	cost of equipment, training- pruning material, repairs, and other supplies	10,000
Total			**10,33,800**

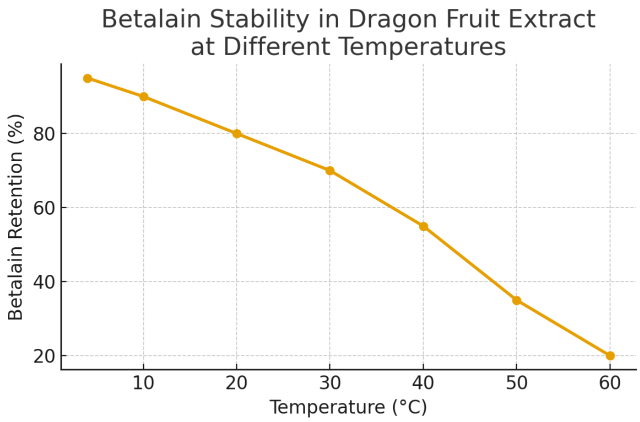

Fig. 1 : Betalain stability of dragon fruit extract at different temperatures

Table 5 : Major categories of dragon fruit value-added products and benefits

Product Category	Examples	Key Benefits
Dehydrated snacks	Slices, chips	Shelf stability, fibre-rich
Juices & beverages	RTS, blends, probiotic drinks	Antioxidant-rich, functional
Jams & jellies	Blended jams, peel jellies, candies	Value from peel, antioxidants
Bakery goods	Bread, buns, cookies	Colour, fibre, antioxidants
Powders & extracts	Spray-dried juice, peel pigments	Natural colourant, nutraceutical
Industrial uses	Bioplastics, cosmetics	Waste valorisation, sustainability

Table 6 : Effect of drying methods on quality of dragon fruit chips

Drying Method	Processing Time	Color Retention	Antioxidant Retention
Hot-air drying	Long	Low	Low
Freeze-drying	Long	High	High
Microwave-vacuum	Short	Moderate	Moderate-High
Refractance window	Moderate	Good	Good

Sustainability and Circular Economy Opportunities

Valorisation of peel and other by-products into pectin, pigments, fibre supplements, animal feed or biobased materials embodies circular economy principles. Microbial fermentation of waste to bioethanol or high-value metabolites has been demonstrated at lab scale (*Tripathi et al.,* 2023). Integrating waste valorisation reduces environmental footprint and creates additional revenue streams.

Research Gaps and Future Directions

Despite growing literature, several gaps remain: (i) scale-up studies for extraction and pigment stabilisation; (ii) long-term shelf-life and sensory studies for novel formulations; (iii) robust life-cycle analyses for bioplastic and biofuel applications; (iv) standardised protocols for seed oil extraction and protein recovery; and (v) pilot studies to evaluate socio-economic impacts of processing enterprises on smallholders.

Conclusion

Dragon fruit represents a multipurpose crop with wide potential for value-added product development from both edible and non-edible parts. Adoption of appropriate processing technology, standardisation of methods and integration of circular-economy practices are critical to unlock its full potential. Addressing agronomic and postharvest constraints alongside investments in value chain infrastructure will determine how successfully dragon fruit moves from a premium fresh fruit to a diversified industrial platform.

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