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C Nithya
 Department of Processing and
 Food Engineering, Kelappaji
 College of Agricultural
 Engineering and Food
 Technology, Tavanur,
 Malappuram, Kerala, India

Recent innovations and opportunities in red dragon fruit (*Hylocereus polyrhizus*) juice processing and value addition: A review

C Nithya

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Abstract

Red dragon fruit (*Hylocereus polyrhizus*) is gaining global recognition for its striking appearance, high nutritional value, and diverse health benefits. Research suggests that regular consumption of this fruit may lower the risks of chronic diseases—including diabetes, cancer, and atherosclerosis—while supporting liver and kidney health, primarily due to its rich antioxidant and anti-inflammatory profile. To meet rising consumer demand and maximize its economic potential, innovative processing and value addition are essential for ensuring year-round availability. This review discusses recent advancements in red dragon fruit juice processing, comparing traditional thermal methods with emerging non-thermal techniques such as high-pressure processing, thermosonication, ultrafiltration, and pulsed light, which show promise in preserving bioactive compounds and maintaining sensory quality. Furthermore, the development of value-added products—including fermented beverages, wines, jellies, syrups, and carbonated drinks—is explored, with fermentation noted for its potential to enhance the nutritional profile of the final product. Despite extensive research on the composition of dragon fruit pulp, studies on its juice remain limited, underscoring the need for further investigations to optimize preservation strategies and unlock its full commercial and therapeutic potential.

Keywords: Non-thermal processing, Pitaya, red dragon fruit, thermal processing, value addition

Introduction

Red dragon fruit (*Hylocereus polyrhizus*) also known by various names such as Pitaya, Pitahaya, Strawberry pear, Kamalam, Buah Naga, and the wonder fruit of 21st century is gaining global recognition due to its high consumer demand and numerous health benefits. Research has shown that its consumption can help reduce the risk of diabetes, cancer, and atherosclerosis while supporting liver and kidney health. Additionally, the fruit is rich in antioxidants and possesses strong anti-inflammatory properties, making it a valuable addition to a healthy diet (Nishikito *et al.*, 2023)^[35].

To ensure year-round availability and maximize its economic potential, processing and value addition of dragon fruit are essential. Developing innovative processing methods not only extends the shelf life of the fruit but also enhances its usability in various food and beverage applications. This review explores recent advancements in dragon fruit juice processing, including both thermal and non-thermal techniques. Additionally, it highlights recent research on value-added products derived from dragon fruit, emphasizing their potential benefits for both consumers and the agricultural industry.

Dragon fruit varieties

Dragon fruit (*Hylocereus spp.*) is a tropical fruit from the cactus family (*Cactaceae*). According to Arivalagan *et al.* (2021)^[3], there are five main species, each identified by its skin and pulp color. *H. undatus* has pink skin and white pulp, *H. polyrhizus* has pink skin and red pulp, *H. costaricensis* has pink skin with a deep violet-red interior, *H. guatemalensis* has red pulp and a reddish-orange outer layer, and *H. megalanthus* has yellow skin with white pulp. However, Li *et al.* (2024)^[27] noted that molecular studies in 2017 reclassified *Hylocereus* species into the *Selenicereus* genus, which now consists of 33 species.

Corresponding Author:
C Nithya
 Department of Processing and
 Food Engineering, Kelappaji
 College of Agricultural
 Engineering and Food
 Technology, Tavanur,
 Malappuram, Kerala, India

The most commonly grown varieties include *S. undatus* (red peel, white flesh), *S. costaricensis* (dark magenta peel, violet-red flesh), *S. monacanthus* or *S. polyrhizus* (crimson peel and flesh), and *S. megalanthus* (yellow peel, white flesh). Abirami *et al.* (2021) ^[56] reported that only four species-*H. undatus*, *H. monacanthus* (*H. polyrhizus*), *H. costaricensis*, and *H. megalanthus* (*Selenicereus megalanthus*)-are widely cultivated. In India, *H. undatus* is the most commonly grown, particularly in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Punjab, and West Bengal.

Production statistics

Chen & Paull, (2019) ^[4] noted that precise production data for dragon fruit remains limited due to its relatively recent emergence as a tropical fruit crop. However, Al-Qthanin *et al.* (2024) ^[2] reported a global production estimate of 2,100,777 metric tons, with India contributing 12,200 metric tons (1% of total production) and ranking ninth. Vietnam leads global production, accounting for 43%, followed by China, Indonesia, Thailand, and Taiwan. Meanwhile, Li *et al.*, (2024) ^[27] identified China as the top producer in terms of both cultivation area and yield. The significance of dragon fruit in tropical fruit production has grown substantially, ranking as the fifth most important subtropical horticultural fruit in South Asia, after lychee, longan, banana, and mango. The fruit originated in Mexico, as well as the central and southern regions of America (Sharma *et al.*, 2021) ^[44].

In India, dragon fruit is actively cultivated in Maharashtra, Karnataka, and Gujarat (Kakade *et al.*, 2020) ^[57], with cultivation expanding in Kerala, Tamil Nadu, Odisha, West Bengal, and the Andaman and Nicobar Islands.. The majority of dragon fruit available in the Indian market is imported from Thailand, Vietnam, Philippines and Malaysia (Karunakaran *et al.*, 2023) ^[20]. Dragon fruit, a member of the Cactaceae family, can be grown at a density of 800 plants per hectare. Once planted, the plant continues to produce fruit for up to 20 years. The fruit is available for harvest over a seven-month period, from May to December

(Perween *et al.*, 2018) ^[58]. In kerala, the season slightly varies from March to October.

Red dragon fruit pulp and juice composition

Arivalagan *et al.* (2021) ^[3] studied biochemical and nutritional content of different varieties of dragon fruit. The study reported that dragon fruit is a nutrient-rich, low-calorie superfruit with high mineral and vitamin content. It starts yielding within 12-15 months and stabilizes by the third year. White-pulped varieties have higher yield and sugar content, while red-pulped ones are richer in phenolics and antioxidants. Among the clones, Hirehalli White excelled in yield and quality, while Hiriur Round Red and Long Red were best among red varieties. This study provides valuable nutritional data, promoting dragon fruit as a healthy dietary choice.

Lande *et al.* (2024) ^[22] studied two types of dragon fruit: white-fleshed (*H. undatus*) and red-fleshed (*H. polyrhizus*). The red variety was shorter but wider and heavier than the white one. White dragon fruit had a slightly higher juice yield than the red variety. The red dragon fruit contained more sugar, protein, vitamin C, and minerals like calcium, magnesium, and phosphorus. In contrast, the white variety had more fat and carbohydrates and appeared brighter in color. The red dragon fruit was the only one with betacyanin and had higher levels of phenolic compounds in both pulp and juice. These differences show that both types have unique benefits and can be used in various food products like drinks and ice cream.

Chakraborty *et al.* (2024) ^[59] investigated how different extraction and processing methods affect the antioxidant activity of dragon fruit. Their study highlighted the fruit's rich antioxidant content, including phenolic acids, flavonoids, and betalains, found in the pulp, peel, seeds, and leaves. The peel showed the highest antioxidant activity, with the DPPH assay being the most commonly used measurement method. Storing dragon fruit at 5°C helps maintain freshness, while advanced extraction techniques like UAE and MAE improve antioxidant retention, making the fruit valuable for both health benefits and food preservation.

Table 1: Proximate Composition, biochemical and physicochemical properties of red dragon fruit pulp and juice

Properties	Composition of red dragon fruit pulp	Composition Red dragon fruit juice
Moisture (%)	82-85	88
Protein (%)	0.90-1.1	0.66
Fat (%)	0.57	0.13
Total sugars (%)	5.13-7.06	8
Non-reducing sugars (%)	1.8	1.24
Reducing sugars (%)	3.3 -7.0	4.5-5.6
Ash (%)	0.7- 0.85	0.5
Dietary fibre (%)	0.8 -1.1	0.41
Total Phenolic content (mg GAE/100g)	25 - 55	41.25
Total flavonoid content (mg CE/100g)	15 - 35	15-30
Betalains (mg BCE/100g)	14 - 23	21.11
DPPH radical scavenging activity (%)	70-80	70-80
pH	4.8-5.4	4.2
TSS	9-11	11
Colour values		
L*	12-13	0.8-0.9
a*	34-35	3 - 4
b*	9-9.5	0.25-3.0
Vitamin C (mg/100 g)	12.75	9.9
Titrateable acidity (%)	0.3-0.48	0.28- 0.45
Mineral composition (mg/100 g)		

Potassium	195	62
Phosphorous	27.85	8.67
Magnesium	20.43	7.45
Calcium	6.75	2.45
Iron	5.59	0.95

References: Islam *et al.* (2012) ^[15], Abd Manan *et al.* (2019) ^[1], Arivalagan *et al.* (2021) ^[3], Kumar, (2021) ^[21], Lande *et al.* (2024) ^[22].

Chuah *et al.* (2008) ^[60] analyzed the rheological properties of dragon fruit juice, which are crucial for optimizing equipment design, process control, and consumer acceptance. Juice concentrates of 10° and 12°Brix were prepared, and their flow behavior was examined at temperatures of 5, 10, 15, and 40°C. The results indicated that dragon fruit juice exhibits non-Newtonian, pseudoplastic behavior, with both concentrations fitting well within the selected rheological model. Additionally, the effect of temperature on apparent viscosity was best described using the Arrhenius model.

Red dragon fruit juice Processing

Enzyme assisted extraction of juice

Nur 'Aliaa *et al.* (2011) ^[36] explored the impact of commercial enzymes, Pectinex Ultra SP-L and Pectinex CLEAR, on the chemical composition, vitamin C, and polyphenol content of red pitaya juice. Results showed no significant changes in key nutrients like moisture, fat, carbohydrates, and calories after enzymation and pasteurization. However, the use of Pectinex CLEAR notably increased protein content from 0.23% to 2.20%. While vitamin C levels slightly decreased due to heat treatment, phenolic compounds rose by 7%, enhancing the juice's antioxidant properties. These findings provide useful insights for optimizing red pitaya juice production and promoting it as a functional beverage.

Truong & Dang, (2016) ^[49] evaluated the effectiveness of using two commercial enzymes, Pectinex Ultra SP-L and Viscozyme L, to enhance the extraction process and quality of red dragon fruit (*Hylocereus polyrhizus*) juice. The enzymes were applied at a constant total concentration of 0.1%, but their ratios, temperatures, and treatment durations varied. Their application significantly boosted both juice yield and quality. The highest yield and sugar content were obtained at 40°C after 120 minutes using a 70/30 enzyme ratio. In contrast, juice extracted without enzymes had a lower yield and sugar content. Moreover, enzymatic treatment lowered viscosity, increased acidity, and improved total phenolic content (TPC) and vitamin C levels compared to non-enzymatic extraction.

Minh, (2020) ^[31] examined how different pectinase concentrations (15 to 35 µL/100 mL) and incubation times (30 to 90 minutes) at 35°C affect the turbidity and viscosity of pitaya juice. The results indicated that treating the juice with 30 µL/100 mL of pectinase for 75 minutes at 35°C significantly improved its clarity and consistency, making it more suitable for subsequent membrane-based clarification processes.

Dao *et al.* (2023) ^[9] explored how pectinase affects the quality of red-fleshed dragon fruit juice. Pectinase (400 ppm) was tested at different concentrations (0-9%) and hydrolysis times (0-45 min). Juice quality was measured by recovery efficiency, pectin content, betacyanin content, viscosity, and total phenolic content. The best results were achieved with 5% pectinase and 25 minutes of hydrolysis,

leading to 88.16% hydrolysis efficiency, low pectin (0.49 g), low viscosity (1.15 cP), and high betacyanin (20.06 mg/100 mL) and phenolic content (88.68 mg/100 mL).

Pham *et al.*, (2024) ^[42-43] explored how cultivation conditions and geographic origin influence the phytochemical composition and antioxidant properties of red-fleshed dragon fruit from four regions in Vietnam. The study also focused on refining pectinase enzymatic hydrolysis and thermal sterilization techniques to enhance juice quality. Additionally, an optimized energy drink formulation was developed to improve nutrient preservation, microbial safety, and consumer acceptance. The research identified optimal processing parameters, including a pH of 4.6, a temperature of 53°C, a treatment time of 145 minutes, and an initial enzyme concentration of 0.24%.

Ultrasound assisted enzymatic extraction

Le & Le. (2021) ^[24-25] optimized ultrasonic and enzymatic treatments for maximum antioxidant extraction from red dragon fruit juice using response surface methodology (RSM) with the Box-Behnken design. The best conditions for betacyanin release were 18.4 minutes of sonication and 88.5 minutes of enzymatic treatment at 33.0°C, while for total phenolic content (TPC), the ideal conditions were 13.4 minutes of sonication, 71.5 minutes of enzymatic treatment, and 43.9 °C. LC-MS analysis and antioxidant tests (DPPH and FRAP assays) confirmed that ultrasound-assisted enzymatic treatment improved betacyanin and related compounds. While TPC-focused optimization slightly degraded betacyanins, it significantly increased the juice's overall antioxidant capacity.

Thermal Processing of dragon fruit juice

Conventional heating

Wijitra *et al.* (2013) ^[51] heated white-flesh (WF) and red-flesh (RF) dragon fruit purees from 50 to 90°C for up to 60 minutes to study their physicochemical, color, betacyanin content, microbial, antioxidative, and rheological changes. Unheated RF had significantly higher physicochemical and antioxidative properties than WF. Betacyanin content in RF decreased by 32.35% after heating at 90 °C for 60 minutes, with color changes following second-order kinetics. The L* and b* values were useful for quality control, and TCC could predict betacyanin content. Heating increased antioxidative properties, with strong correlations among them. Both WF and RF exhibited shear-thinning behavior, and heating increased viscosity, fitting well with the power law model. Heated RF puree, in particular, shows potential for food applications due to its beneficial properties.

Liaotrakoon *et al.* (2013) ^[29] studied the effects of heat on white-flesh and red-flesh dragon fruit purees. Red flesh dragon fruit puree initially had higher antioxidant and physicochemical values than WF. Heating RF at 90°C for 60 minutes reduced its betacyanin content to 32.35%. Color change and betacyanin loss followed a predictable pattern, with L* and b* values useful for quality control. Heating improved antioxidant properties in both purees and increased viscosity, following the power law model. Overall, heated Red fleshed dragon fruit puree showed

promising potential for use in food products due to its enhanced properties.

Wong & Siow, (2015) ^[52] examined how heat pasteurization, pH adjustment, ascorbic acid addition, and storage conditions affect betacyanin content in red-fleshed dragon fruit (*Hylocereus polyrhizus*) juice and concentrate. The concentrate was prepared using a rotary evaporator at 40 °C, and betacyanin content was analyzed using a UV-Visible spectrophotometer. The best conditions for preserving betacyanin were 0.25% ascorbic acid, pH 4.0, and pasteurization at 65 °C for 30 minutes. Agitation at 220 rpm improved betacyanin stability in concentrate compared to juice, while light exposure reduced stability in both. Overall, ascorbic acid helped maintain betacyanin levels, but light caused degradation.

Siow & Wong, (2017) ^[46] assessed how juice concentration affects betacyanin degradation and sensory acceptance in red-fleshed dragon fruit (*Hylocereus polyrhizus*) juice. Findings showed that samples stored at 4°C retained betacyanin better and had lower yeast and mold growth compared to those stored at 25°C. Betacyanin degradation in both juice and concentrate followed a first-order reaction at 25, 37, and 45°C. Additionally, reconstituted juice from the concentrate was preferred for its sweetness, flavor, and overall acceptability. The study highlights that juice concentration can enhance both betacyanin stability and sensory appeal.

Ohmic heating

Doan *et al.* (2023) ^[11] explored how ohmic heating and ascorbic acid affect the quality of red-fleshed dragon fruit juice during storage. The juice was heated to 85°C using ohmic heating and stored at 4°C for eight weeks. After one week, there was no significant loss of phenolic content or betacyanin, but by week eight, betacyanin dropped by 47%, total phenolic content by 60%, and antioxidant activity by 39%. Color changes were closely linked to betacyanin levels. Compared to conventional heating, ohmic heating preserved more nutrients. Adding 0.25% ascorbic acid helped maintain color, betacyanins, Total phenolic content and antioxidant activity, making ohmic heating a better method for processing and storing the juice.

Non-thermal processing of dragon fruit juice

UV -C light

Halim *et al.* (2012) ^[13] explored application of ultraviolet-C (UV-C) light to reduce microbes in red pitaya juice (RPJ) and assessed the added effects of citric acid and dimethyl dicarbonate. UV-C treatment alone decreased total plate counts by 2.43 log₁₀ and yeast and mold counts by 2.7 log₁₀. Adding 1.5% Citric acid and 15 µL/100 mL Dimethyl dicarbonate further lowered microbial levels. Combining these additives with UV-C treatment resulted in greater reductions: 4.12 log₁₀ for Total plate count and 4.14 log₁₀ for Yeast and mould count, outperforming UV-C treatment alone.

Ochoa-Velasco & Guerrero-Beltrán, (2012) ^[40] treated Pitaya juice with continuous UV-C light at 57 µW/cm² using five flow rates (0.46, 3.28, 6.57, 16.49, and 30.33 mL/s) and five treatment durations (5, 10, 15, 20, and 25 minutes), with untreated juice as a control. The treatment did not significantly alter pH or total soluble solids. However, longer treatment times resulted in greater overall color change (ΔE), although higher flow rates helped lessen

this effect. In addition, increased treatment time and lower flow rates led to reductions in betalains and total phenolic compounds, which decreased the juice's antioxidant activity. Furthermore, the UV-C processing effectively reduced microbial counts, achieving up to a 2.11 log cycle reduction in aerobic mesophilic bacteria and a 1.14 log cycle reduction in yeasts and molds.

Ochoa-Velasco & Beltrán, (2013) ^[39] treated fresh pitaya juice deliberately inoculated with the yeast *Zygosaccharomyces bailii*, with continuous UV-C light at 57 µW/cm². The juice was processed at three different flow rates (16.49, 23.78, and 30.33 mL/s) with treatment times ranging from 5 to 30 minutes, and then stored at 4 °C for 25 days. Throughout storage, both microbiological (yeasts, molds, and total counts) and physicochemical (pH, soluble solids, color, phenolic content, betalains, and antioxidant activity) properties were monitored. Longer UV-C exposure led to a higher overall color change (with a maximum ΔE of 3.9), and the most intense treatment (30.33 mL/s for 30 minutes) resulted in reductions of 11.6% in phenolic compounds, 14.6% in betalains, and 37.0% in antioxidant activity, as well as a 1.8 log cycle drop in the population of *Z. bailii*.

Ozone- high hydrostatic pressure

del Rosario García-Mateos *et al.* (2019) ^[10] explored the combined effects of ozone (24 mg/O₃/L/min) and high hydrostatic pressure (HHP, 179-321 MPa) on reducing microbes in pitaya juice. The most effective treatment-ozone for 7 minutes followed by 316 MPa for 5 minutes-significantly reduced *Listeria innocua* and *Saccharomyces cerevisiae*, keeping native microbes at undetectable levels. Juice treated this way had the highest sensory preference (79%) after 30 days at 5°C. The findings suggest that using ozone and HHP together is more effective for ensuring juice safety than using them separately.

Ultrasound processing

Liao *et al.* (2020) ^[28] evaluated the effects of thermosonication (TS) on the color stability of clear red pitaya juice. While longer treatment and higher temperatures caused color changes, TS retained color better than thermal processing (83°C, 1.5 min). The color shift was mainly due to betacyanin decomposition, confirmed by spectroscopic analysis, with betanin and phyllocactin degradation playing a key role. Increased 5-hydroxymethylfurfural and Maillard reaction products also contributed to discoloration. However, TS effectively inactivated polyphenol oxidase and preserved over 92.97% of polyphenols, minimizing enzymatic browning. These findings suggest that TS is a promising method for maintaining color and bioactive compounds in fruit juice.

Zhu *et al.* (2021) ^[55] examined the effects of thermosonication (TS) on the microbial safety and quality of red pitaya juice during storage. Juice treated with TS (475 W, 56°C for 20 minutes) experienced a significant reduction in microbial count, comparable to conventional thermal processing (83°C for 1.5 minutes). Over 28 days of refrigerated storage at 4°C, essential quality attributes such as pH, soluble solids, enzyme activity, and browning remained stable. However, slight color deterioration was observed after 10 days due to betacyanin degradation and residual microbial activity. Compared to thermal processing, TS provided better color preservation while maintaining a

similar shelf life, making it a viable alternative for juice preservation.

Tan *et al.* (2023) ^[48] examined the effects of ultrasonic pretreatment on the physicochemical properties of red dragon fruit juice. Flesh cubes were subjected to ultrasound for 20, 40, and 60 minutes using an ultrasonic bath operated at an output power of 600 W and a frequency of 37 kHz. While total soluble solids, pH, and titratable acidity remained unchanged, a 60-minute treatment significantly increased organic acids, phenolics, and anthocyanins compared to untreated juice. Antioxidant activity was also positively influenced by sonication duration. These results indicated that ultrasonic pretreatment can enhance the nutritional profile of red pitaya juice.

Ultrafiltration

Le *et al.*, (2021) ^[24-25] studied the clarification of red-fleshed dragon fruit juice using ultrafiltration (UF) with polyethersulfone membranes of different pore sizes. The best results were obtained with a 10 kDa membrane at 3 bar, achieving high filtration efficiency while preserving betacyanins and phenolic compounds. Cake resistance was the main factor affecting filtration, while membrane structure remained unchanged after use and cleaning. Liquid chromatography-mass spectrometry confirmed that UF effectively clarified the juice without damaging heat-sensitive compounds.

High Pressure Processing

Ismail *et al.* (2024) ^[16] examined the effects of high-pressure processing (HPP) and thermal pasteurization (TP) on the preservation of red dragon fruit (RDF) purée. The study analyzed total betacyanin content, phenolic and flavonoid levels, antioxidant activity, enzyme activity, microbial growth, and color stability over 60 days of storage at 4±1°C. RDF purée samples were divided into TP-treated (65°C/20 min), HPP-treated (350 MPa/5 min), and an untreated control group, with analyses conducted at 15-day intervals. Results showed that preservation method and storage duration significantly influenced these attributes. HPP was highly effective in extending shelf life beyond 60 days by suppressing microbial growth and reducing enzyme activity, whereas TP helped maintain phenolic content, antioxidant activity, and color stability. These findings suggest that HPP offers a promising alternative to TP for RDF purée preservation, promoting sustainability and health-conscious food practices.

Pulsed light

Kamble *et al.* (2024) ^[19] evaluated the effects of thermal and pulsed light (PL) processing on red dragon fruit juice preservation at 4°C. Thermal treatment (95°C for 3 minutes) and PL treatment (1.4 J cm⁻²) effectively reduced microbial content, and the juice was stored in ethylene vinyl alcohol pouches under refrigeration. Over 30 days, no significant changes were observed in pH, titratable acidity, or total soluble solids. However, thermal processing led to greater losses of total phenols (36%) and antioxidants (22%) compared to PL treatment. The shelf life was 25 days for PL-treated juice and 30 days for thermally treated juice. The findings highlighted PL as a promising alternative for preserving dragon fruit juice with minimal nutrient loss.

Value added products from red dragon fruit juice

Dam, (2012) ^[8] optimized protocols for producing various products from different parts of *Hylocereus undatus* fruits

and plant. The best wine formula used 50% (v/v) *S. oviformis* and 50% (v/v) *S. vini*, yielding 12% ethanol. Betacyanin extraction required pre-drying at 55°C and a 1:5 raw material-to-water ratio, yielding 14.82%. Jam was produced using 0.3% pectinase and 0.2% pectin for optimal texture and taste. Soft drinks from stems were made with 0.25% Pectinex Ultra SP at 45-55°C, a 1:4 material-to-water ratio, 10.4% sugar, and pasteurization at 95°C. Dragon fruit flower tea, made with 10% dried flowers, licorice, citric acid, and sugar, had superior quality to other teas in the Vietnamese market.

Ombiko & Lascano, (2016) explored the use of red-fleshed dragon fruit in fruit juice drinks, cream cheese spreads, and yogurt drinks. Four juice formulations (1:3, 1:5, 1:7, and 1:10 juice-to-water ratios) were developed, with Treatment A (highest juice content) having the highest titratable acidity and vitamin C, while Treatment B (1:5 ratio) was the most acceptable. Dragon fruit was also incorporated into cream cheese spreads as jam and puree (0-35%), with the 35% formulation selected for its cost-effectiveness. Chemical tests showed higher antioxidant activity in the puree (68.54%) than in the jam (60.60%), while the jam-flavored spread had the highest viscosity. To utilize surplus dragon fruit, a yogurt drink was developed with varying puree concentrations (0-20%). Higher puree levels increased pH, total soluble solids, and antioxidant activity while decreasing viscosity. Sensory analysis identified the 15% puree formulation as the most preferred, though 10% and 20% were also acceptable.

Jelly

Islam *et al.* (2012) ^[15] analyzed the nutritional composition of dragon fruit and develop dragon fruit jelly to evaluate its market potential. The proximate analysis of juice showed high moisture (87.90%), total sugar (8.00%), vitamin C (9.90%), and a pH of 4.20. Jelly was prepared using different pectin concentrations (0.05%, 0.1%, and 1.5%) and analyzed for nutritional content. All samples had similar compositions and were stored at room temperature (27°C-34°C) for six months. Minimal changes in color, flavor, and pH were observed after four months. A taste panel of 10 participants rated the samples, with the 1.5% pectin jelly scoring highest in color, flavor, turbidity, and overall acceptability.

Fermented drink

Choo *et al.* (2018) ^[5] examined how storage temperature and duration affect fermented red dragon fruit drink (FRDFD). Results showed that betacyanin content and physicochemical properties were better preserved at 4°C than 25°C. Microbial counts remained low, and after eight weeks at 4°C, FRDFD retained 13.93 g/L betanin with a pH of 3.46. Sensory evaluation showed over 80% acceptability, confirming its potential as a functional beverage.

Choo *et al.* (2019) ^[6] optimized fermentation conditions to increase betalain concentration in fermented red dragon fruit drink (FRDFD). The study examined fermentation duration, sugar-to-flesh ratio, and sugar type. The optimal condition-7 days of fermentation with 10% white refined cane sugar-produced the highest betanin, total phenolic, and flavonoid content, achieving a nine-fold increase compared to non-optimized fermentation. This demonstrates fermentation as an effective and economical method to enhance bioactive compounds in functional beverages.

Huan *et al.* (2020) ^[14] optimized the alcoholic fermentation of Vietnamese dragon fruit juice using *Saccharomyces cerevisiae*. Experiments tested different sugar levels (16-20°Brix), yeast inoculum (1-3%), and fermentation times (40-48 hours). The best conditions were found to be 18°Brix sugar, 2% yeast, and 44 hours of fermentation, resulting in 3.54% alcohol and 14.6°Brix residual sugar. Sensory evaluation rated the drink as "moderately like."

Wine

Jiang *et al.* (2020) ^[18] studied the impact of pectinase pre-treatment on red dragon fruit wine fermentation using *Torulaspora delbrueckii*. After juice pasteurization, Pectinex® Ultra SP-L (0.1% v/v) was added, and fermentation occurred at 20°C for 14 days. The results showed no significant effect on yeast growth, ethanol, or glycerol levels, but juice and wine yield increased by 16% v/v. Fermented samples with pectinase retained more nitrogen-containing compounds, indicating less favorable fermentation conditions. The treatment enhanced ester and terpene aromas while reducing higher alcohol content. Although total phenolic content increased, betacyanin levels and color intensity were lower than in untreated samples. These findings suggested that pectinase treatment can improve juice yield and aroma while influencing fermentation conditions and color properties, providing insights for red dragon fruit wine production.

Ngoc *et al.* (2024) ^[33] optimized fermentation conditions for red dragon fruit (*Hylocereus polyrhizus*) wine, focusing on yeast strain, dilution ratio, and yeast concentration (Begum MA *et al.*, 2024) ^[7]. *Saccharomyces cerevisiae* RV002 was the best strain due to its resilience. A 50% dilution ratio improved clarity and flavor, while dilutions above 90% lowered ethanol content. The ideal 1 g/L yeast concentration balanced alcohol production and microbial control. Fermentation reduced sugar and vitamin C but increased polyphenols and antioxidants.

Carbonated drink

Mai *et al.* (2022) ^[30] developed a carbonated drink from red-flesh dragon fruit while optimizing hydrolysis and pasteurization to preserve bioactive compounds and color. The research examined pectinase hydrolysis by varying temperature (35-50°C), time (1-4 hours), enzyme concentration (0.4-1%), and enzyme content (0.2-0.8%). Optimization was based on polyphenol content, vitamin C levels, and antioxidant activity (DPPH scavenging).

Pham *et al.* (2024) ^[42-43] optimized pectin hydrolysis to enhance the quality of red dragon fruit carbonated beverages. The study identified optimal conditions-49.9°C, 131.3 minutes, and 0.23% pectinase-resulting in improved clarity and high anthocyanin content. Sensory evaluation found that a blend of 20% juice, 0.12% citric acid, 13°Bx, and 0.30% mint flavor had the highest consumer acceptance. These findings highlight red dragon fruit's potential for nutritious and appealing carbonated beverages.

RTS drink

Jalgaonkar *et al.* (2018) ^[17] developed a ready-to-serve (RTS) drink using dragon fruit (60-80%), grape juice (0-10%), and sugar syrup (2-6%). The formulation was optimized using response surface methodology with a Box-Behnken design to enhance nutritional and sensory qualities. Results showed that adding grape juice and sugar syrup

significantly improved taste and overall acceptability. The optimal blend consisted of 70% dragon fruit, 5% grape juice, and 3% sugar syrup, producing a nutritionally balanced and well-accepted beverage.

Ghorband & Joshi, (2023) ^[12] formulated a dragon fruit RTS (Ready-to-Serve) beverage using varying concentrations of dragon fruit juice (10-14%), sugar (10-15%), and citric acid (0.3-0.9%). The optimized formulation, determined based on sensory and biochemical analyses, consisted of 14% fruit juice, 12.75% sugar, and 0.38% citric acid. This combination enhanced key quality attributes, including color, flavor, taste, and overall acceptability. Additionally, the beverage exhibited a total soluble solids (TSS) content of 15.70°Bx, an antioxidant activity of 26.44% DPPH inhibition, and an improved color value (a*) of 1.49 with increasing juice concentration. Notably, the absence of artificial colors and flavors ensured the product's nutritional value and safety for consumption.

Patel & Bhise, (2024) ^[41] developed a lime-flavored dragon fruit RTS beverage and evaluated thermal, microwave, and chemical treatments for shelf-life enhancement. The optimized formulation contained 12% fruit juice, 12°Brix TSS, 0.1% citric acid, and 3% lime juice for the best taste. Treatments included thermal (70-90°C for 5-15 min), microwave (900 W for 30-150 sec), and chemical (500-1500 ppm ascorbic acid), with the best results observed at 70°C for 5 min, 900 W for 30 sec, and 500 ppm ascorbic acid. Shelf-life analysis showed significant changes in pH, TSS, betacyanin content, and sensory properties, with the highest betacyanin retention and acceptability on the 6th day at ambient storage, while refrigeration retained higher betacyanin and acceptability on the 60th day. The 500 ppm ascorbic acid treatment proved most effective in maintaining quality during storage.

Pigment

Woo *et al.* (2011) ^[54] investigated the stability of betalain pigment from red dragon fruit extracted with ethanol. They analyzed the effects of storage conditions, pH, light, temperature, and additives over three weeks. The study found that light was the primary cause of betalain degradation, while refrigerated storage in darkness effectively preserved pigment quality.

Concentrated juice

Nguyen *et al.*, (2021) ^[34] studied a novel evaporation method, JEVA, to concentrate juice from Binh Thuan Province, Vietnam, under ambient pressure and moderate temperature. This process increased juice concentration from 13.8°Brix to over 60°Brix while retaining over 90% polyphenols and flavonoids, along with 70.17% vitamin C and 74% betacyanin. Compared to vacuum evaporation at 40°C, which retained 57% vitamin C and 40% betacyanin, JEVA at 35°C preserved 85.76% betacyanin and 81.55% vitamin C after 8 weeks at 4°C. These findings highlight JEVA's potential for large-scale red dragon fruit juice processing.

Kumar, (2021) ^[21] processed dragon fruit juice and concentrate by heating the pulp at 85±2°C (3 minutes for juice, 35 minutes for concentrate), followed by the addition of 0.1% sodium benzoate and 0.1% ascorbic acid. The juice was then cooled and centrifuged at 3600 rpm for 10 minutes. A study on storage stability using different preservative proportions and colored PET bottles showed

that key biochemical properties, including total sugars, acidity, ascorbic acid, and betacyanin, were best preserved in select treatments. After 90 days, the concentrate retained high total soluble solids (TSS) and antioxidant content, confirming that preservatives and packaging effectively improved shelf life.

Nectar

Minh *et al.* (2019) ^[32] aimed to enhance market value of the fruit by optimizing the production and preservation of dragon fruit (*Hylocereus undatus*) nectar. The research evaluated the effects of pH, sugar concentration, pasteurization conditions, and storage parameters on sensory quality, total soluble solids, acidity, and microbial stability. The results indicated that the optimal nectar formulation was achieved at pH 4.2 with 8% sugar, subjected to pasteurization at 95°C for 1 minute, and stored at 4±2°C in glass bottles to maintain quality and stability.

Syrup

Susilo *et al.* (2021) ^[47] aimed to enhance the quality of red dragon fruit (*Hylocereus costaricensis*) syrup by using a double jacket vacuum evaporator to reduce nutrient loss. Traditional syrup production involves high temperatures, which can degrade essential nutrients like vitamin C. The research analyzed the impact of temperature and vacuum pressure on syrup quality through nine treatment variations. Findings revealed that temperature significantly influenced vitamin C levels, moisture content, and reducing sugars, whereas pressure mainly affected moisture content. The best condition for maximizing vitamin C retention (8.75 mg/100 ml) was 50°C at -60 cmHg, highlighting the benefits of low-temperature, low-pressure evaporation in preserving nutritional value.

Syrup is a thick sugar solution that may contain additives. It typically uses high-calorie cane sugar, which can contribute to obesity if not balanced with physical activity. Wibowo & Herawati, (2023) ^[50] examined the effects of low-calorie sugar on the chemical (pH, vitamin C, reducing sugars, betacyanin), physical (total dissolved solids), and sensory (aroma, taste, color) characteristics of red dragon fruit syrup. The experiment followed a randomized block design (RBD) with five sugar concentrations (3%, 6%, 9%, 12%, and 15%), each tested five times, totaling 25 trials. Results showed that low-calorie sugar significantly affected reducing sugar levels and total dissolved solids but had no significant impact on pH, vitamin C, or betacyanin. Sensory tests revealed that panelists preferred the syrup with 15% sugar for its aroma, taste, and color.

Wibowo & Herawati, (2023) ^[50] examined how adding red dragon fruit juice affects the characteristics and sensory qualities of *belimbing wuluh* syrup. A completely randomized design (CRD) was used with five juice concentrations (0%, 5%, 10%, 15%, and 20%) and three replications. Results showed that the juice significantly influenced color, pH, sugar content, vitamin C, acidity, antioxidant activity, and betacyanin levels, while aroma remained unaffected. The best formulation, with 20% juice, had the highest overall quality, including a pH of 3.67, 73.99% sugar, 16.19 mg/100g vitamin C, and strong antioxidant activity (44.65%). Sensory evaluation indicated the highest preference for color, taste, and overall acceptability.

Candy: Nurhafsa *et al.* (2023) ^[38] examined the impact of red dragon fruit peel and pulp on the chemical composition

and acceptance of jelly candy. Using a completely randomized design, different amounts of pulp (50g, 55g, 60g, and 65g) were tested. Chemical analysis measured water content, sugar content, and vitamin C, while 25 panelists evaluated texture, aroma, color, and taste using a five-point hedonic scale. The most preferred formulation (P3) contained 150g peel, 60g pulp, and 290g sugar flour, with a water content of 25.6%, sugar content of 53.7%, and vitamin C of 0.03%.

Singh *et al.* (2023) ^[45] examined the effects of different sugar levels on dragon fruit candy's quality and storage stability. The experiment followed a randomized design with eight treatments. The candy was made using gelatin and citric acid, with the 80% sugar formulation showing the best quality in terms of taste, texture, and chemical properties. Over 90 days of storage at 30°C, sugar levels and acidity increased, while moisture, pH, and sensory quality slightly declined. A cost-benefit analysis showed all treatments were profitable, with the highest return in the 55% sugar formulation.

Juice powder

Lee *et al.* (2013) ^[26] investigated the stability and antioxidant properties of spray-dried red and white dragon fruit powder under varying humidity conditions. The powder was produced using spray drying at 120°C for red dragon fruit and 110°C for white dragon fruit, with 30% maltodextrin as a carrier. The resulting particles ranged from 3 to 7 µm in size. While spray drying reduced the antioxidant content, the antioxidant properties remained stable after 25 days of storage. Structural changes were observed at 43%, 54%, and 75% relative humidity (RH), whereas 33% RH preserved the stability of the powder.

Nurhadi *et al.* (2024) ^[37] examined the stability of encapsulated betacyanin from dragon fruit peel and pulp using maltodextrin and gum Arabic as coating agents with vacuum drying. Findings indicated that juice powder maintained higher phytochemical concentrations and stability compared to ethanol-extracted peel powder over 30 days. Although both powders exhibited similar color stability, juice powder retained a more natural fruit-like hue but had lower antioxidant activity. Betacyanin levels were higher in juice powder than in peel powder. The combination of maltodextrin and gum Arabic (1:1) proved most effective in preserving total phenolics and betacyanin, highlighting its potential for industrial applications.

Value added products from dragon fruit peel

Pectin: Woo *et al.* (2010) ^[53] conducted a study on the extraction and characterization of pectin from dragon fruit peel obtained from the fruit industry. The peel was oven-dried, and pectin extraction was carried out at varying pH levels (3.0, 3.5, and 4.0) and subjected to heat treatment at 75°C for different durations (30, 60, and 120 minutes). The findings indicated that the highest pectin yield was achieved at a pH of 3.5 with a treatment time of 60 minutes.

Conclusions

This review highlighted recent advancements in dragon fruit processing, with a particular focus on juice preservation and value addition. While extensive research has been conducted on the composition of dragon fruit pulp, studies on its juice remain limited, necessitating further investigation into its bioactive compounds. Non-thermal preservation techniques

such as high-pressure processing (HPP), thermosonication, ultrafiltration, and pulsed light have shown promise in maintaining juice quality, though the potential of pulsed electric fields, cold plasma, and retort processing remains largely unexplored. Additionally, the development of value-added products, including fermented beverages, wine, jelly, syrup, and carbonated drinks, enhances the commercial viability of dragon fruit. Notably, fermentation has been found to increase bioactive compound content, further improving the fruit's nutritional profile. Future research should focus on optimizing preservation techniques and exploring novel processing methods to maximize the health benefits and shelf life of dragon fruit products.

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Authors' contribution

C Nithya: Conceptualization, Literature collection, Investigation, Methodology, Software, Visualization, Writing -original draft

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