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Postharvest Profile, Processing and Waste Utilization of Dragon Fruit (*Hylocereus Spp*.): A Review

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ABSTRACT

Dragon fruit is a nutritious and wonderful exotic fruit cultivated throughout the arid regions of the globe, particularly Asian countries. The fruit with an attractive shape and magnificent color are refreshing with mouthwatering taste. It is abundant in vital nutritional ingredients *viz*. carotene, calcium, fiber, vitamin B, vitamin C, and phosphorous. The fruit is processed into numerous value-added products; however, that has been limited to small-scale processing industries. In addition to pulp processing, the utilization of by-products (peel, seed) will contribute to reducing waste disposal problems, imparts value to the product for food and other industrial applications. Further, extraction and application of bioactive compounds from fruit waste having the application for food fortification can enhance the overall efficacy of the process. This review highlights the technologies and processes adopted for the overall utilization of dragon fruit. Further to make rational usage of this valuable resource, systematic compilation and presentation of reported literature are required. Therefore, the present work was aimed towards the comprehensive utilization of this fruit through value addition approaches and by-product utilization.

KEYWORDS

Dragon fruit; postharvest processing; by-product utilization; value addition

Introduction

Dragon fruit, known as pitaya or pitahaya belongs to *the Cactaceae* family and is prevalent in two separate genera namely, '*Hylocereus*' and '*Selenicereus*'. The most common commercially cultivated varieties are from *the Hylocereus* genus covering around 16 different species.[1] It is also called as strawberry pear, *thangloy* (Vietnamese), *pitayaroja* (Spanish), and *la pitahaya rouge* (French). The fruits are grown on climbing cacti with 6 meters long stem[2 and the areas with less annual rainfall are more suitable for cultivation. Pitaya species are mostly found in Mesoamerica in varied landscapes ranging from few meters to 1700 m above sea level and 500 to 2000 mm rainfall.[3] The cultivation is prominent in about 20 countries including Thailand, Indonesia, Taiwan, Vietnam, Srilanka, Bangladesh, Japan, Malaysia, Philippines, Australia, United States, and China. India is an importer of dragon fruit nevertheless the cultivation area is increasing nowadays. There are three varieties that are grown commercially includes, *Hylocereus undatus* (white dragon fruit), *Hylocereus polyrhizus* (red dragon fruit), and *Selenicereus megalanthus* (yellow dragon fruit).[4 The market price of this fruit in the country is around 150–200/kg and sometimes

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even higher than this. Owing to its ornamental importance and consumption for table purposes, the fruit has great potential in national as well as international markets. The ultimate benefit of growing dragon fruit is that once planted, it will develop for around 20 years and one hectare is capable of accommodating about 800 plants. More significantly it is a quick return perennial crop with production begins in the subsequent year after planting and full production within 5 years can be achieved.

Dragon fruit being highly perishable requires more attention from cultivation, harvesting, handling, storage, processing, and transportation till market distribution. Since the major quantum of fruit undergoes for fresh consumption, establishing an adequate and sound marketing channel for transportation to distant places presents a big challenge. In this regard, postharvest research and development efforts must be intensified to bolster the industry. From the perspective of processing, dragon fruit has been utilized for the preparation of valorized products like juice, jam, jelly, powder, wine, etc.

Owing to its nutritional attributes and commercial importance, the significance of dragon fruit in the processing industry cannot be overlooked. Reported literature also signifies the attempts made by researchers on various aspects associated with processing, value addition, and waste utilization of dragon fruit. However, a systematic review is lacking in the reported literature inferring the various approaches/techniques of processing and by-product utilization of dragon fruit. Therefore, the available information has been compiled and presented in this review emphasizing the research and technological perspectives related to the fruit.

Physiology and structure

Being non-climacteric in nature, dragon fruit provides the best quality for consumption when it is harvested ripe as the quality diminishes during storage.[5] At optimum maturity, it has ample amount of small black seed with a bright red/yellow skin and white/coloured flesh depending on the type of cultivar.

Dragon fruit consists of three principal components, pulp (47.40–73.76%), peel (36.70–37.60%), and seed (2.70–14.67%).[6,7] The colour of fruit pulp may vary from white to various hues of red and purple.[8] Peel of red or yellow colour is observed in dragon fruit. Also, the red colour of peel is deeper in red dragon fruit than white fruit.[9] Seeds are tiny, soft in texture, edible and black coloured.

The most common growing varieties of dragon fruit are illustrated in Table 1. These fruits have a very low ethylene production rate of 0.03–0.09 µl/kg/h. The ethylene application to the fruit does not result for colour development.[11,12] Respiration rate attains its peak (75–144 mg CO_2/kg/h at 20–23°C) during the early stages of fruit growth.[11,12]

Maturity traits

The foremost maturity criterion is change in the skin colour to almost either red or yellow depending upon the cultivar. The other indices include size, weight, soluble solids content (SSC), pulp betacyanins, flavor rating while the minimum value for firmness, mucilage, starch content, and titratable acidity (TA), and a minimum of 32 days from flowering.[12,13] Usually, a 40:1 ratio of SSC with TA was recommended as an optimum

Table 1. Morphological characteristics of different varieties of dragon fruit.

Characteristics	White dragon fruit (*Hylocereus undatus*)	Red dragon fruit (*Hylocereus polyrhizus*)	Yellow dragon fruit (*Selenicereus megalanthus*)
Fruit Shape	Oblong	Round	Oblong
Pulp colour	White	Red-violet	White
Peel colour	Red	Red	Yellow
			

Chik et al.[10]

harvest index instead of considering them alone as a measure of maturity.[13] During winter, colour break happens 30 days after flowering (DAF), and fruits are ready for harvest at 33–34 days and during the summer season, colour break happens after 26 days and picking at 30 DAF.[14] Sometimes, in the international market, consumers prefer less sweet dragon fruit. In such cases, fruit can be harvested earlier or later than 31 DAF for less sweet or sweeter taste fruit, respectively.[11]

Harvesting and grading

Harvesting of fruit is to be done after the attainment of physiological maturity and completion of developmental stages.[15] The absence of peduncle makes the harvesting of dragon fruit difficult. The most common practice followed for harvesting is, twisting the fruit manually which often damages the skin. To overcome this, knife/secateurs can be used which is carried out with two cut operation and can be speeded up by one cut with a pair of shears.[16] Pictorial representation of harvested dragon fruit is shown in Fig. 1.

Based on the physical characteristics, dragon fruit is classified into three categories *viz.* extra, class I and class II as described in Table 2. [18] In addition to the above classification, the fruits are also graded on the basis of the weight. Red/white dragon fruits are graded in nine different size codes and yellow fruit is graded in five different size codes as mentioned in Table 3. [18] The grading is also performed on the number of fruits per 4-kg cardboard box, i.e. 6, 8, 10, 12, 14, or 16.[2]

It is apparent that manual method for grading of dragon fruit is followed and there is a definite need for adoption and implementation of advanced grading techniques which can grade the fruit based on physical attributes, optical properties or weight, etc. Variation in the characteristics of different cultivars must be carefully considered while designing

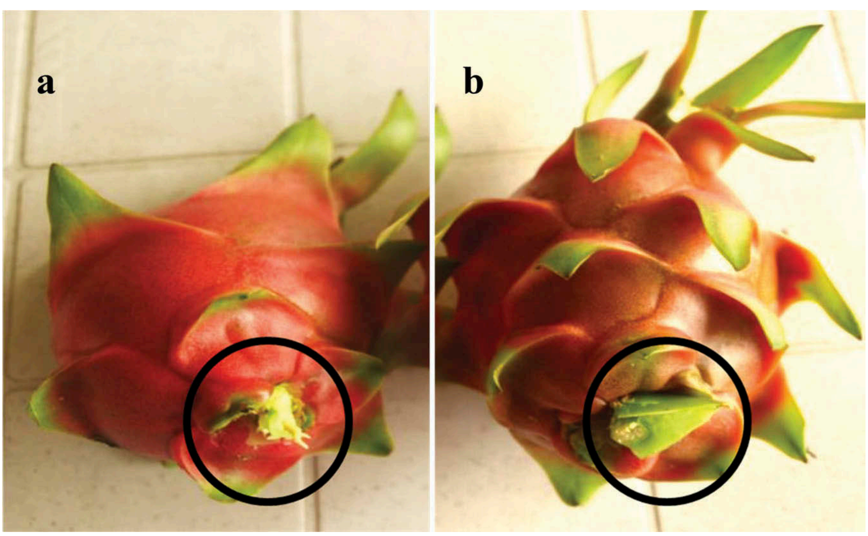


Figure 1. Harvested dragon fruit by twisting method (a) and by knife/secateurs (b). Philippine National Standard[17]

Table 2. Classification of dragon fruit.

Classification	Requirements
Extra	• Superior quality • Must be characteristics of the variety/and or commercial type • Free of defects with the exception of very slight superficial defects which do not affect appearance, quality, and packaging, • Tolerance: Five percent by number or weight of dragon fruit not satisfying the requirements of the class, but meeting those of Class I or, exceptionally, coming within the tolerances of that class
Class I	• Good quality • Must be characteristics of the variety/and or commercial type • Slight defects in shape • Slight defects of the skin not exceeding 1 cm^2 of the total surface area of the fruit • Defects should not affect the fruit pulp • Tolerance: Ten percent by number or weight of dragon fruit not satisfying the requirements of the class, but meeting those of Class II or, exceptionally, coming within the tolerances of that class
Class II	• Fruits do not include in the upper class but should satisfy the minimum requirement such as whole, sound, fresh in appearance, free of any visible foreign matter and pest, etc.] • Slight defects in shape • Slight defects of the skin not exceeding 2 cm^2 of the total surface area of the fruit • Ten percent by number or weight of dragon fruit satisfying neither the requirements of the class nor the minimum requirements, with the exception of produce affected by rotting or any other deterioration rendering it unfit for consumption

Codex Alimentarius[18]

Table 3. Grading of dragon fruit based on unit weight.

	Unit weight (g)	
Size code	Red/White	Yellow
A	110–150	110–150
B	151–200	151–200
C	201–250	201–260
D	251–300	261–360
E	301–400	>361
F	401–500	–
G	501–600	–
H	601–700	–
I	>701	–

Codex Alimentarius[18]

any relevant machine. The research in this domain should be need based keeping in view of the demands of entrepreneurs/industries and its adoption to small scale.

Postharvest disorders

Chilling injury, decay, mechanical injury, and moisture loss are the main postharvest disorders associated with dragon fruit. Chilling injury can occur at the temperature level of 5–6°C; however, it depends on the species, maturity level at harvest and growing location. Fruits that are harvested early are more prone to chilling injury which is characterized by flesh translucency, softening, wilting, darkening of scales, browning of the outer flesh and poor flavor. The mechanical injury occurs due to skin abrasion making the fruit unappealing and intensifies the rate of water loss resulting in shriveling. Fully mature fruits are highly vulnerable towards mechanical damage/injury.[11] In order to minimize/restrict the skin abrasion and compression injury, the harvested fruits need to be cautiously handled and packaged in protective containers. The fruit is vulnerable to moisture migration and physiological loss in weight (PLW) which ranges from about 0.1% (5ºC) to 2.6% (20ºC) for *H. undatus*. Appropriate packaging of fruit in perforated plastic bags while maintaining required relative humidity (RH) can reduce PLW to as low as 0.05% at 5ºC and 10ºC. Water loss resulted in unsightly shriveling as well as reduction in fruit weight. Optimum maturity, suitable harvesting time, and proper packaging are the key factors that determine the nature and extent of injury to dragon fruit. The reported information regarding postharvest disorders, symptoms, probable causes, and remedies have been compiled and presented in Table 4.

Therefore, there is a need to modify the fruit environment after harvest that can slowdown these deteriorative processes and extend its shelf life while maintaining the physicochemical properties which are essential from nutrition and health point of view.

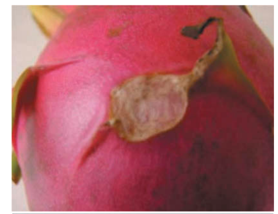
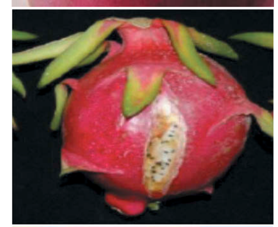
Storage

The postharvest storage life is affected by the rate of respiration and PLW. Recommended storage temperature for dragon fruit (*Hylocereus undatus* and *Hylocereus polyrhizus*) is 10° C[13] and for yellow pitaya (*Selenicereus megalanthus*) it is 6°C[12] with 85–90% RH. Storage life at 10°C and 5°C with 90% RH was reported as 14 and 17 days, respectively.[11] Nerd et al.[13] stored *Hylocereus polyrhizus* for 2 weeks at 6°C that maintained the fruit quality, however, upon transferring the fruits to 20°C for the next 7 days, they became soft and unacceptable. In another study conducted by the same authors, loss in flavour after 2 weeks at 14°C in *H. undatus* was reported. Chilling injury to the fruit peel was also reported when the fruits were stored for 14 days at 6°C initially and subsequently for 7 days of storage at 20°C. *H. undatus* was successfully stored for 21 days at 5°C with an insignificant reduction in flavor and acceptable external quality.[21] Quick softening of fruits along with decrease in sugar and acidity was observed at a storage temperature of above 20°C.[22] The location of fruit cultivation also governs the response to lower temperature as *H. undatus* grown in California withstood storage at 5°C for 20 days while maintaining a glossy external appearance and negligible internal injury.[23]

Obenland et al.[24] highlighted that storage of six different varieties (Cebra (C, red, *H. costaricensis*); Lisa (L, red, *H. costaricensis*); Rosa (R, red, *H. costaricensis*); San Ignacio (SI, red, *H. costaricensis*); Physical Graffiti (PG, light pink, *H. polyrhizus* × *H. undatus*); Mexicana (M, white, *H. undatus*)) at 5°C and 10°C resulted in a slight darkening of inner pulp colour. Non-significant effect of storage on overall visual liking, flavour, sweetness, texture, or color of the peel was observed. The antioxidant activity was decreased while fruit storage at 5°C but remains unaltered at 10°C, with the concentration of betacyanin was same as that was predicted at harvest.

For Indian market, even though the growth in production data is encouraging, but still most of the fruit comes via export and therefore maintaining the quality parameters throughout the marketing channel is pertinent. However, it is quite difficult to maintain the optimum temperature (5°C and 10°C) and RH (90%) all the time during transit. Therefore, the losses during various phases of storage are critical but can be minimized by proper handling, packaging practices. and by extending the accessibility of cold storage facilities either to the farmers or nearby production catchments. The accessibility, storage capacity, feasibility, and cost factors are the important parameters that need to be considered before adopting the advanced storage systems by the growers.

Table 4. Postharvest disorders associated with Dragon fruit.

Disorders	Symptoms	Probable cause	Remedies		Reference
Chilling injury	• Flesh translucency • Fruit softening • Fruit wilting • Darkening of scales • Browning of outer flesh • Poor flavour	• Early harvested fruit [25 days from flowering] than that which was harvested 30–35 days after flowering • Temperature below the range between 5°C and 10°C	• Storing the fruit between 5°C and 10°C. However, it varied for each genetic background, growing environment, and ripening stage at harvest		[2, 12, 11]
Mechanical injury	• Development of sunken areas on fruit surfaces	• More mature fruit is susceptible to mechanical injury	• Can be avoided by harvesting fruit at the appropriate ripeness stages and by careful handling after harvest		[11]
Fruit splitting	• Rupturing/cracking of peel	• Harvesting of fruit >35 days from flowering, where rainfall or excessive irrigation during ripening may have been received	• Proper harvesting		[11]
Rapid shrivelling	• Reduces visual quality, storage life, and marketability	• Weight loss and desiccation as a result of transpiration	• Packing of fruit in perforated plastic bag which reduces water loss and rapid shrivelling		[19, 20]

Kruger and Lemmer[14]

Effect of pre-treatment on shelf life

The key factors that deteriorate the fruit quality after harvest include the spoilage due to the micro-organisms as well as the rapid physiological processes of the fruit. Factors like weight loss, increased ripening, and high respiration which cause shriveling of dragon fruit after eighth day of harvesting are responsible for its short storage life.[25] The physiological processes need to be slowdown to maintain the quality and to enhance the storage life of fruit. Different physical and chemical treatments have been developed to preserve the dragon fruit such as edible coating, heat treatment, chemical treatment, and packaging.

Hoa et al.[21]observed that heat treatment (46.5°C for 20 min) to 'Binh Thuan' fruit core followed by storing at 5°C in perforated polypropylene (PP) bags (25 µm) restricted fruit fly infestation up to 4 weeks. Whereas, heat treatment (55°C for 15 min) followed by bagging in perforated polyethylene (PE) plastic bag prolonged its shelf life for up to 21 days at 10°C storage temperature and 90% RH as against about 6 to 7 days for fruits bagged in PE plastic with holes when stored at 25–30°C.[26] Chutichudet and Chutichudet[27]reported that chitosan coating (3%) increased the storage life of dragon fruit upto 8.17 days compared to untreated fruit (7.02 days) under conditions (27°C and 88% RH). Zahid et al.[28]revealed that treating dragon fruit with 0.50% of ethanolic extract of propolis along with 70% ethanol for 2 min for uniform coating followed by drying (20 ± 2°C) and storing (20 ± 2°C, 80 ± 5% RH) for 20 days not only curtailed the ripening process but also augmented biosynthesis of nutritional constituents. In another study conducted by Ali et al.[25] dragon fruit was immersed in chitosan dispersion solution (600 nm) for 15 min and then dried overnight at room temperature followed by dipping in 1.0% chitosan solution for next 5 min. This treatment was found effective in increasing the storage life up to 28 days when stored at cold storage (10 ± 2°C and 80 ± 5% RH) without the development of off-flavour. Alvarez-Herrera et al.[29] revealed that 1-methylcyclopropene (600 mg/liter) in vaporized form for 24 h was effective to maintain the quality characteristics of yellow pitahaya for about 28 days in a way by reducing the respiration and chlorophyll degradation. Mustafa et al.[30]pre-treated the dragon fruit with four different concentrations of salicylic acid (SA) (0.1, 1, 2 and 5 mM) and methyl jasmonate (MJ) (0.01, 0.1, 0.2, and 0.5 mM) at cold storage conditions (6°C) for 21 days. During the experiment, it was observed that low dose of SA delayed process of ripening whereas, MJ increased betacyanins as well as antioxidant activity and showed a non-significant effect on ripening.

Dragon fruit is more prone to the fungal contamination by *Rhizopus, Fusarium, Botryosphaeria*, and *Colletotrichum* which can easily damage the fruit during storage.[25,28] To overcome this, Chaemsanit et al.[31] placed peppermint oil (100–-1000 µl/l) with dragon fruit in the storage box for 21 days (25 ± 2°C, 75 ± 5% RH). The peppermint oil adsorbed activated carbon at a concentration of 700 µl/l was found to prevent the growth of *Penicillium, Aspergillus niger*, and *Rhizopus* with 100% inhibition on fruit surface and decay fungi beyond 14 days of storage whereas untreated fruits start decaying at 7 days of storage.

Consumer's perception of the fruit quality is not only dependent on external appearance and aesthetic quality but also on its nutritional properties. As the fruit progress towards ripening, consistent variations in the physical and chemical parameters are obvious. There are notable changes in bioactive contents which also affect the aesthetic and nutritional properties of the fruit. Evidently, these changes do not follow the same pattern and are influenced by factors like cold storage and stress hormones. In this direction, future studies can be formulated to explore the effect of combination of different stress regulating hormones on dragon fruit.

Effect of packaging material and storage condition on shelf life

Packaging of fruit in different packaging materials is a promising approach to reduce rapid shriveling and water loss during storage. The various approaches involving the packaging of dragon fruit are presented hereunder:

Dragon fruit were harvested after 28–30 days of flowering and successfully kept for 35 days at 10°C under modified atmosphere (MA) in PE bag (O_2 transmission rate 4000 ml/m^2/day), whereas the control samples were retained afresh for only 14 days. The more matured fruits (40 DAF) in the same MA bag exhibited 50% lower shelf life.[11] According to Zee et al.[32] the fruit quality was acceptable for 25–30 days when stored in perforated plastic bags at 4.5°C, however, when stored at room temperature the shelf life was less than 10 days. Garcia and Robayo[33] found that wrapping of green pitahaya in non-perforated PE wrap with storage at 10°C resulted in the shelf life of 18 days and 21 days with a less than 5% and 10% rate of deterioration, respectively. Chandran[34] reported that dragon fruit (*Hylocereus polyrhizus* and *Hylocereus undatus*) wrapped using cling packaging (0.8 µm) were stored up to 15 days at 6°C compared to 9 days at 24 ± 1°C (Fig. 2). Sutrisno and Purwanto[35] recommended that storing dragon fruit in MA containing 2–4% of O_2 and 6–8% CO_2 at 10°C enhanced the storage

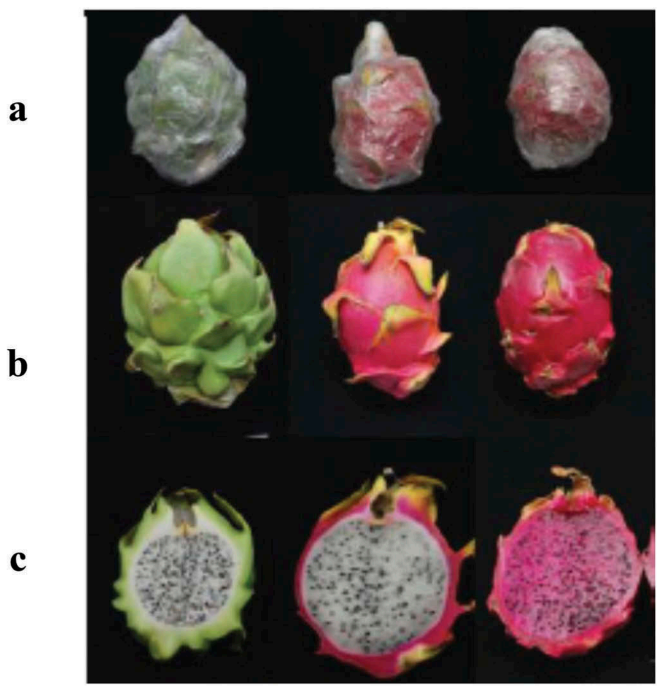


Figure 2. Best results obtained at 6°C after 15 days of storage. All three stages of fruits (a) remained unchanged and appeared fresh both on the exterior (b) and the pulp (c).
Chandran[34]

duration to 25 days with stretch film and styrofoam plate of dimensions 120 × 180 mm. Similarly, De Freitas and Mitcham[23] stored the dragon fruit at three different storage conditions (5°C, 7°C, and 10°C) with or without perforated (holes of 10 mm diameter) in 20 µm low-density polythene bags which was followed by 5 days storage at 20ºC without bags. The best results were obtained at storing fruit in a non-perforated plastic bag at 5°C with less decay and low level of chilling injury. However, the application of perforated plastic bags can be employed to decrease weight loss if it is paired with decay controlling strategies during storage. Rodeo et al.[36] wrapped individual fruit in PE and PP bags, fitted inside the polystyrene (PS) cups and stored at 5°C. PE showed better results in terms of higher firmness, total soluble solids and TA than PP bags. However, non-significant difference was observed between two packaging material in terms of shelf life. Also, the use of PS cups improved the fruit quality by giving safety to bracts from damaging/breaking during transport, handling, and storage.

The PLW during storage and handling is very critical. There is a necessity to use suitable packaging material in combination with effective decay controlling strategies which not only reduce the weight loss but also increase the shelf life during storage. Moreover, it is essential that the packaging material should be of low cost, easily available and environmental friendly.

Processing and waste utilization

Each part of dragon fruit (pulp, peel, seeds, flower buds, dried flowers) has tremendous nutritional value in terms of antioxidants, fiber, vitamin C, minerals, especially calcium, and phosphorus. Some of these important properties are illustrated in Table 5. Owing to these

Table 5. Nutritional composition of different parts of Dragon fruit.

	Pulp	Peel	Seeds
Moisture (g/100 g of pulp)	82.5–89.4[d]	84.86–91.19[a,b]	12.6 ± 6[h]
pH value	4.26–4.98[c]	4.83–5.48[b]	3.1–6.1[k]
Dry matter (%)	12 ± 1[e]	NR	NR
Density 20°C (g/cm^3)	1.02–1.04[c]	NR	NR
Titratable acidity (%)	3.15–6.85[c]	0.22–0.25[b]	NR
Total soluble solids (°Brix)	7.50–12.92[c]	7.15–12.77[b]	NR
Total soluble solids: Titratable acidity	10.93–35.20[c]	4.60–5.70[k]	NR
Pectin (mg/g)	0.64–1.36[c]	NR	NR
Fat content (%)	0.10–0.61[d]	0.02–0.07[b]	29.6 ± 6[h]
Ash content (%)	0.28–0.50[d]	14.29[a]	2.1 ± 1[h]
Mineral content	NR	0.17–0.22[b]	NR
Total phenolic content (mg/100 g)	3.75–19.72[g]	28.16–36.12[g]	1356 ± 2.04[i]
Total dietary fiber (g/100 g)	1.1–3.20[f]	69.30 ± 0.53[j]	30.2 ± 19[h]
Total ascorbic acid (mg/100 g)	13.0–55.80[f]	NR	NR
Total Vitamin C (g/1000 ml)	0.32–0.58[c]	0.0704–0.0762	0.0036 ± 0.01[i]
Protein content (g/100 ml)	12-12.5[e]	0.64–0.66[b], 0.95 ± 0.15[j]	20.6 ± 6[h]
Citric acid (g/100 ml)	9.5–21.1[c]	0.08 [j]	NR
Malic acid (g/100 ml)	60.8–82.0[c]	0.64 [j]	NR
Glucose (g/100 ml)	491.4–1039.5[c]	4.15 ± 0.03[j]	NR
Fructose (g/100 ml)	192.0–289.7[c]	0.86 ± 0.02 [j]	NR
Betacyanin content (mg/g of dm)	NR	41.55[a]	NR
Total carbohydrates (%)	NR	6.20 ± 0.09[j]	35.2 ± 15[h]

The reported values are concerned with only three major species (*Hylocereus undatus, Hylocereus polyrhizus, Selenicereus megalanthus)* of dragon fruit.
a[37], b[46], c[6], d[3], e[15], f[38], g[39], h[40], i[41], j[42], k[10], NR represents not reported.

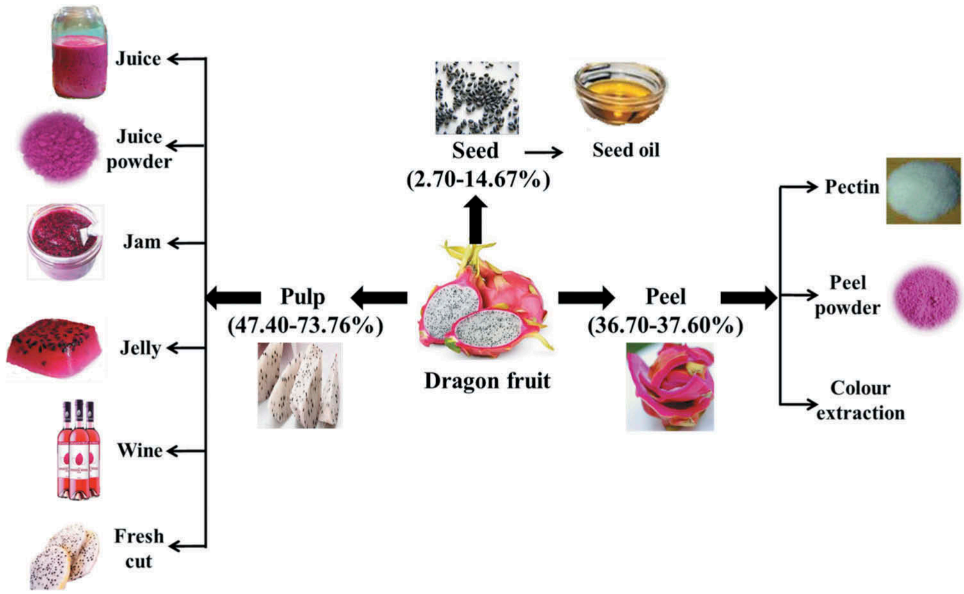


Figure 3. Different processed/valorized products that can be prepared from dragon fruit.

nutritional attributes, the fruit got attention from the researchers and can be processed into different products (Fig. 3). The fruit peel has potential as an antibacterial agent[39], natural colorant, and antioxidant.[43] Apart from the nutritional benefits of mature fruit, the young stem, and fresh flower buds are also edible and can be used as a vegetable.[44,45] The dehydrated dragon fruit flowers were used for making antioxidant-rich tea.[3]

Minimal processing has been practiced for the preparation of products to preserve the essential sensory attributes. The fruit pulp used to make juice, wine, jam, jelly, and preserve. Peel has utilization for the extraction of natural food colorant as well as a source of pectin. Seeds are mainly utilized to extract the oil from it which contains about 50% essential fatty acids.[20] Also, the seeds have application as an ingredient in many food products such as syrup, ice cream, sherbet, candy, yogurt, and pastries.[3] The subsequent section contains a detailed description of the efforts made by several researchers about the processing aspects of dragon fruit:

Fresh cut or minimal processing

The information about the minimal processing of dragon fruit on pilot scale is very limited. Goldman et al.[47] reported that cutting/slicing did not aggravate fruit deterioration, but the cut slices adhered together during storage and were difficult to separate which may be improved by the application of suitable edible coatings. The peeled and/or sliced dragon fruit packed in microperforated packages maintained its organoleptic, visual, and microbiological quality for at least 14 days at 4°C or 8°C storage (Table 6). Low molecular weight chitosan (molecular weight = 12.36 ± 0.17 kDa, 95–98% deacetylated and viscosity 630 mPas; VA&G Bioscience Inc., Taoyuan, Taiwan) coating (0.2%, 0.5%, and 1.0%) on sliced pitayas followed by 7 days storage at 8°C reduced water loss (from 86.93% to

Table 6. Microbiological quality of fresh cut dragon fruit (CFU/g).

Product	Monitoring day	Enterobacteria (CFU/g)	*E. Coli* (CFU/g)	Yeast (CFU/g)	Molds (CFU/g)
Acceptable threshold levels		<5000	Not found	<20,000	<5000
Fresh peeled dragon fruit	After 4 days transit	<100	Not found	<100	1000
Stored peeled dragon fruit	After 5 days storage at 6°C	<100	Not found	2000	1000

Goldman et al.[47]

70.43%), thus maintained SSC (from 12.42° to 12.36°B), TA (from 0.17% to 0.14%), ascorbic acid (AA) content (from 9.0 to 7.8 mg/100 ml) with improved flavour quality, inhibited microorganism growth, juice leakage, and prevented surface browning. The control fruits were unacceptable while the chitosan-coated fruits retained quality characteristics after 1 week.[5] Frozen pulp is reported to be a marketable product having great marketing potential as the product is not subjected to quarantine for fruit fly.[3] Chansamrankul et al.[48] emphasized that the shelf life of fresh-cut fruit depends upon the number of days fruit has been harvested and stored at ambient temperature. They prepared fresh-cut fruit using the fruits which were stored for 0, 2, 4, and 6 days after harvesting at approximately 30°C followed by packing in foam trays and wrapping with polyvinyl chloride film and then storing at 4°C. Shelf life of 10 days was reported of the fresh-cut products prepared from the fruits stored for 0, 2, and 4 days after harvesting, whereas the shelf life of fresh-cut product prepared using the fruit stored for 6 days was reported as 8 days. This decline in shelf life was due to the onset of translucent flesh tissue in the fruit.

Application of $CaCl_2$ at higher concentration for longer duration on fresh-cut fruit showed lower activity of polygalacturonase (PG) and pectin methylesterase (PME) enzymes without affecting its quality.[49] The optimum conditions for osmotic dehydration of dragon fruit cubes (1.5 ± 0.1 cm) were reported as 30°C of temperature, 55% of sucrose concentration, 6% salt concentration, and 270 min of immersion time.[50] Li et al.[51] pointed out that cutting of dragon fruit in different styles (quarter, half, and full slice of 10 mm thickness) did not show adverse impact on the organoleptic properties, but considerably influenced biosynthesis of phenolics and enhanced antioxidant activity of sliced fruit. Moreover, reactive oxygen species may act as signaling molecules in the phenolic accumulation in pitaya fruit induced by wounding stress.

Juice

Basically, consumers prefer low viscous, more clear and high nutrition fruit juice which is rich in vitamin C, total polyphenols contents, and antioxidant activity. The main compounds accountable for antioxidant activity of dragon fruit are phenolic compounds and betacyanin[52, 39] Higher turbidity as well as viscosity with colloidal suspension is the unique characteristics of pitaya juices. Therefore, clarification needs to be done for gaining commercial importance and acceptability.[54] Enzymatic treatment is helpful to increase juice yield, stability, and clarity by degrading soluble pectin and starches which are responsible for haziness in juice [53] . Various approaches followed with an aim to improve the juice quality as well as its shelf-life extension are described below:

Herbach et al.[55] emphasized that the application of minimum heat load resulted in retaining two-third of the betacyanins content in pitaya puree after pasteurization. High content of the mucilage in yellow pitaya created problem in juice clarification by filtration process, required a high dose of enzymes and hamper further pigments concentration. However, the presence of mucilage would provide an advantage over minimizing the degradation of betacyanins during heating and storage. In addition, the certifiable hydrocolloids might be profitable while using purple pitaya juice as a colouring foodstuff, hence rendering thickening agents unnecessary. The study recommended that the application of unclarified juice containing total fruit mucilage for dairy products may be beneficial. The stability of pitaya juice storage at 20 ± 2°C can be enhanced by the addition of 1% of AA which decreases the damage caused due to light and provide an opportunity to use clear packaging materials.

For higher retention of betalains which includes betacyanins and betaxanthins, low-temperature enzyme liquefaction process (7.9°C reaction temperature, 3 days reaction time, 0.92% AA concentration, and 1% enzyme dosage) was effective which retained 80% of betalain with reduced viscosity (50%) and increased the juice yield from 25–39% to 48–60%. The study also described that processing of dragon fruit juice into semi concentrate (33% TSS) and full concentrate (65% TSS) after enzyme-assisted pulp liquefaction is a viable option on a pilot scale.[56]

Optimization for enzymatic clarification of fruit juice using Pectinex Ultra SP-L enzyme was performed by Nur Aliaa et al.[54] and the recommended conditions for enzymatic treatment were, 0.06% of enzyme concentration, 49°C of maceration temperature, and 40 min of maceration time to obtain juice yield of 80.3% (v/v). In another study, Nur Aliaa et al., (2011) made an attempt to use commercially available enzymes *viz.* Pectinex Ultra SP-L and Pectinex CLEAR to clarify the red pitaya juice. The clarification using Pectinex CLEAR increased the protein content to 2.20% from 0.23% (w/w) of the raw juice whereas, Pectinex Ultra SP-L raised total polyphenol content by 7% suggesting antioxidant-rich nature of the prepared pitaya beverage.

Moh[57] emphasized that concentrated fruit juice had longer storage life with lesser transportation cost than that of fresh juice. The juice was concentrated using the freeze concentration process performed at different conditions. During this process, stirring rate and cooling medium temperature was varied in the range of 600, 800, 1000, 1200, and 1400 rpm and −6, −8, −10, −12, and −14°C, respectively. Freeze concentration at 1200 rpm of stirring rate and −10°C of cooling medium temperature was found to be an effective way to concentrate the juice (17°brix) as it preserves flavour that originally found in fresh juice. Jayasinghe et al.[58] prepared dragon fruit-based yogurt and reported that the maximum sensory acceptability and nutritive properties consequent upon addition of 10% (w/w) dragon fruit juice, 10% sugar, and 0.8% gelatin. Also, it can be stored at refrigeration conditions (4°C) for 15 days without affecting its quality parameters.

Wong and Siow[59] examined the effect of various process conditions on the betacyanin content of red-fleshed dragon fruit juice and concentrate. The authors reported the optimized processing conditions for maximum retention of betacyanin content, i.e. addition of AA (0.25% w/w) to the juice adjusted to pH (4.0) and pasteurized (65°C for 30 min). Storage at agitation speed (220 rpm) recorded higher betacyanin stability in concentrate as compared to juice, while the stability was on par when stored in light.

Storage of fruit juice in light resulted in degradation of betacyanins whereas, betacyanins present in concentrate did not get affected by storage condition. Also, the combination of different enzymes such as Pectinex Ultra SP-L and Viscozyme in the ratio of 70:30 increased the red dragon fruit juice yield from 54.04 (control) to 86.35% at incubation temperature (40°C) and time (120 min), respectively.[60]

Similarly, Siow and Wong[61] prepared red-fleshed dragon fruit juice (13.5 ± 1°brix) and concentrate (60 ± 5°brix) with the addition of 0.25% (w/w) AA. The pH was adjusted to 4.0 with 1 M HCl followed by pasteurizing (60°C for 30 min) and storing at two different temperatures (4°C and 25°C). AA helped to retain betacyanins content in juice and concentrate. Better retention of betacyanins and no microbial growth (mold and yeast) was observed in the samples stored at 4°C than at 25°C (concentrate 4°C > juice 4°C > concentrate 25°C > juice 25°C). Betacyanin was more stable in concentrate samples compared to juice samples (concentrate 4°C > juice 4°C > concentrate 25°C > juice 25°C). Jalgaonkar et al.[62] prepared functional health drink using 70% dragon fruit juice, 22% of pomegranate juice, 5% grape juice, and 3% sugar syrup with overall acceptability of 8.50.

Dragon fruit juice is one of the most important processed product with wider recognition and attractiveness. In addition, the characteristics like retention of nutritional as well as organoleptic properties along with higher shelf-life, handling ease, and convenience make juice a valuable product for both consumers and food industries. Moreover, from the commercial and industrial perspective, efforts must be directed for establishing the continuous juice processing line for pilot-scale production in the cultivation/catchment area which will increase its global availability.

Juice powder

Dragon fruit powder is very prevalent because of high shelf life, good economic value, and its ease for addition in different processed products as functional foods in the form of natural colorant. Spray drying is an industrial technique utilized for obtaining powder from different fruit juices with maximum retention of nutrients and other active substances. The spray-dried powder has the advantages of readily reconstitution, suitable for transport at ambient conditions which ultimately reduces the cost of transportation compared to raw fruits.[63] But the major drawbacks of stickiness and flow problems of the powder are associated with spray drying of fruit juices[64] which can be overcome using carrier materials such as maltodextrin, gum, starch, lipids, or gelatin as an additive to the feed material during drying.

For obtaining fine and soft dragon fruit powder by spray drying, the best operation condition suggested by Dailami[65] was 180°C of inlet temperature with 20% of maltodextrin. Whereas, the best operating condition to get maximum betacyanin content was 155°C of inlet temperature and 20% of maltodextrin concentration as reported by Tze et al.,[66] Yusof et al.[67] also prepared powder using peeled pitaya slices (0.25–0.30 mm thickness; 100 ± 10 mm diameter) which were dried in an oven (70°C for 48 h) followed by grinding in kitchen grinder to attain particle size of 300 μm. The prepared powder was used to prepare tablets with the addition of maltodextrin (60%) as a binder (Fig. 4). On the contradictory, Lee et al.[68] highlighted that, highest powder yield (around 60%) of spray-dried red and white pitaya fruit was obtained at the

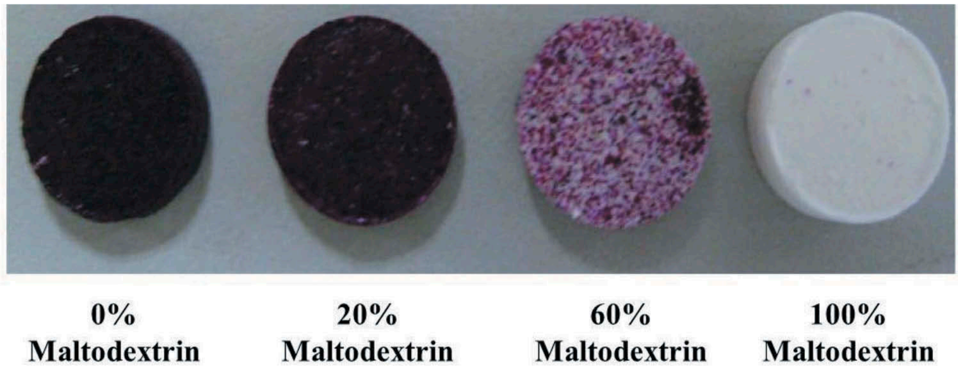


Figure 4. Tablets prepared from pitaya powder. Yusof et al.[67].

threshold inlet air temperatures 120°C and 110°C, respectively, and threshold maltodextrin concentration of 30% (w/v). Storage of red and white fruit powders at 25°C for 25 days with increasing RH at 43%, 54% or 75% showed cracks and structural breakdown with liquefaction (Fig. 5). Storage of powder at 33% RH did not show any visible changes and after storage there was no variation in the antioxidant properties of the powder. It was observed that below the specified spray dryer operating conditions, free-flowing characteristic/nature of the powder was not obtained. Incorporation of dragon fruit juice powder into composite foods helps to meet the nutrient deficiency. However, the possibility of its substitution, effect of serving to the targeted group with specific health problems and different quality aspects of developed products needs to be studied in detail.

Figure 5. Physical changes in spray-dried dragon fruit powder after storage (at 25°C for 25 days). Lee et al[68].

Wine

Fermentation of fruit juices not only improve the shelf life of produce but also enhance flavor attributes and antioxidant potential. Foong et al.[69] made an effort to prepare fermented drink using red dragon fruits and reported 1.42% of betanin as compared to 0.23–0.39% of betacyanin in raw fruit pulp. Pasteurization (75°C for 15 s) of fermented juice indicated a positive effect on bioactive compounds with greater amounts of acetic acids, betacyanins (betanin, isobetanin), phytosterols (campesterol, stigmasterol, β-sitosterol), total flavonoid content, total flavanol assay, and total phenolic content as well as higher ($p < .05$) radical scavenging capacity in ABTS assay as compared to unpasteurized fermented juice. The prepared pasteurized and unpasteurized fermented drinks were confirmed safe for consumption. Similar trends were reported by Wybraniec et al.[70] and Stintzing et al.[71] in their respective studies.

On the similar line, Dam[72] also prepared wine using juice (pH 4.29 and 23.07°Brix) with saccharose and fermented with 2.10 yeast cells/ml at 31–32°C for 7 days followed by 13–16°C for 23 days. Different yeast formulation used (100% *S. cerevisiae* (CT1), 100% *S. oviformis* (CT2), 100% *S. vini* (CT3), 25% *S. ovifomis*, 75% (v/v) *S. vini* (CT4), 50% (v/v) *S. ovifomis*, 50% (v/v) *S. vini* (CT5), and 75% (v/v) *S. ovifomis*, 25% (v/v) *S. vini* (CT6)) showed that CT 5 formulation gave best results in terms of colour, aroma, taste, transparency, and hormony.

For the preparation of fermented red dragon fruit drink, Choo et al.[73] used the fermentation tank (2 L capacity) in which alternate layer of fruit pieces (5 mm thick) and sugar were arranged in the ratio of 5:1 (fruit pieces: sugar) and stored for 8 weeks followed by pasteurization (75°C for 15 s). During the study, the drink was stored at refrigeration (4°C) and ambient (25°C) temperature for 8 weeks. Eighty percent retention of betanin content was observed in drink stored at 4°C. Despite the reduction in betanin during storage, the drink was considered to be sensory acceptable (more than 80% mean score) among the consumers.

Seed separation and oil extraction

Generally, dragon fruit seeds remain closely embedded in pulp and different methods have been used for their separation (Fig. 6). Ariffin et al.[20] have performed an investigation by taking two dragon fruit varieties *viz. Hylocereus polyrhizus* and *Hylocereus undatus*. They used the method for seed separation from flesh which included sterilization of dragon fruit in an autoclave (1 h) followed by separation of peel and flesh, placing the flesh containing seeds in a beaker. Then, the water was added to the beaker and shaken vigourously which ultimately settled down the freed seeds at the bottom which can be recovered using mesh. After the seed separation, seed were over nightly dried (60°C) in the oven and ground using a mortar which was further used for extraction of oil using soxhlet apparatus with petroleum ether (40–60°C) and rotary evaporator was used to evaporate petroleum ether. Seed yield of 1.3% and 1.5% (w.b) and oil yield of 29.5% and 32% were observed from *H. polyrhizus* and *H. undatus*, respectively. Moreover, *H. polyrhizus* and *H. undatus* also contain about 51% essential fatty acids (C18:2 (50%) and C18:3 (1%)) but have lower seed to fruit ratio, i.e. 1:99.

Schweiggert et al.[56] highlighted that seeds are released from their mucilaginous capsule after enzyme-assisted liquefaction (7.9°C reaction temperature, 3 days reaction

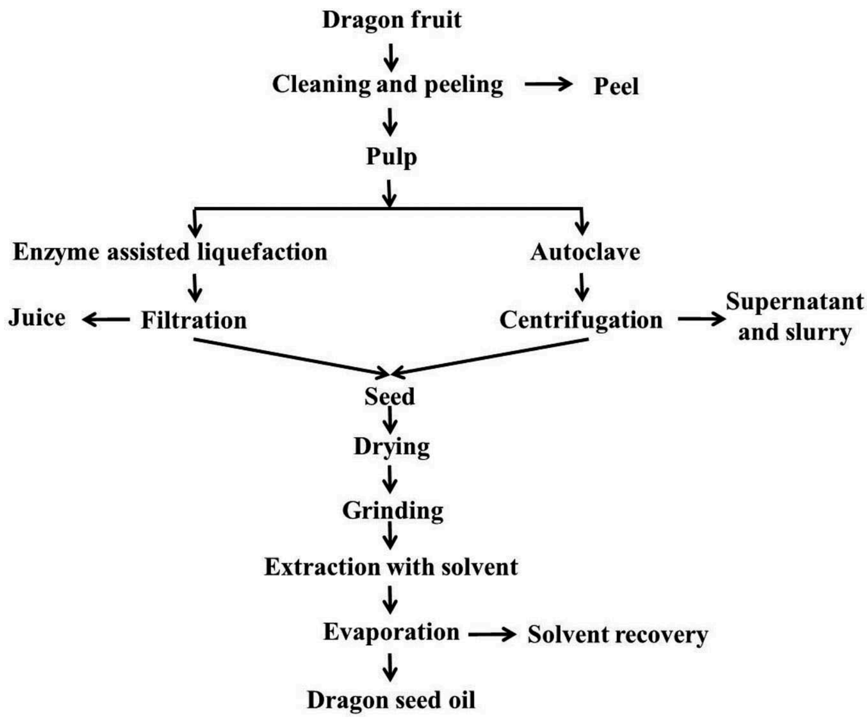


Figure 6. Schematic diagram for seed oil extraction from dragon fruits.

time, 0.92% AA concentration, 1% enzyme preparation). Seed may effortlessly be recouped for oil extraction by juice filtration followed by immediate washing. For the collection of more amount of seeds from dragon fruits, use of sieving machine with <1.0 mm of size was found effective.[7]

Adnan et al.[41] investigated the antioxidant activity of the red pitaya seeds which were ground in a mortar/grinder/mill/and sieved (<0.85 mm particle sized). Approximately 20 g of the sample was subjected to extraction using solvent in the ration of 1:10 (incubator shaker at 30°C, 150 rpm for 24 h) followed by vacuum filtration to remove the seed residue and evaporation in rotary evaporator at 40°C. The oil extraction yield using ethanol, chloroform, and hexane solvents was found to be 15.4%, 34.9%, and 26.9%, respectively. Ethanolic extract showed high radical scavenging activity at 1000 µg/mL (74.76%) compared to choroformic (17.53%) and hexanic extract (18.28%), indicated that seed is a good source of natural antioxidant.

Villalobos-Gutierrez et al.[40] performed oil extraction using hexane in a soxhlet extractor for 2 h. A rotary vacuum evaporator (operated at 60°C) was used to evaporate the hexane in vacuum followed by evaporation of residual solvent in hot air oven (100°C). The seed oil found to have yellowish colour hue which indicated the presence of yellow-coloured pigments. The authors demonstrated that dragon seed oil contains abundant amount of linoleic acid as compared to flaxseed, rapeseed, sesame, and grape seed oils which helps to get relief from flaky or rough skin and maintain skin smooth moist. The seed oil contains palmitic acid C16:0 (182 g/kg of oil), palmitoleic acid C16:1 (3 g/kg of oil), stearic acid C18:0 (49 g/kg of oil), oleic acid C18:1 (239 g/kg of oil), *cis*-11-vaccenic acid (45 g/kg of oil) C18:1, linoleic acid C18:2 (466 g/kg of oil), arachidic acid C20:0 (18 g/kg of oil), saturated fatty acid (249 g/kg of oil), total unsaturated fatty acid (753 g/kg of oil), monounsaturated fatty acid (287 g/kg of oil), polyunsaturated fatty acid C18:2 (466 g/kg of oil). Comparable compositions were earlier reported for other *Hylocereus sp* by Rui et al.[74] Iodine absorption number, saponification number, and free fatty acid values for purple pitaya seed oil were found to be 105.6 g I_2/100 g, 235.7 mg KOH/g, 1.9 mg KOH/g, respectively. The corresponding values for white pitaya seed oil were, 101.2 g I_2/100 g, 194.4 mg KOH/g, and 2.34 mg KOH/g, respectively. Hence, study needs to be done whether the raffination of oil is necessary before consumption to enhance its economic as well as nutritional qualities.

Similarly, Liaotrakoon et al.[75] have extracted the seed oil from white-flesh (*H. undatus*) and red-flesh (*H. polyrhizus*) fruits using cold extraction process with petroleum ether. They emphasized that the presence of mucilage layer between the pulp and the seed makes it difficult to separate the pulp from seeds, the mucilaginous materials were decomposed using an autoclave. Consequently, the pulp was autoclaved (15 psi for 40 min), followed by centrifugation (8000 *g* for 15 min) to separate and recover the seeds. After overnight drying of seeds in an oven (60°C), they were ground into very fine particles and consequently the oil was extracted using the cold extraction process with petroleum ether. Significant amounts of oil (32–34%) and the main fatty acids were linoleic acid (C18:2, 45–55%), oleic acid (C18:1, 19–24%), palmitic acid (C16:0, 15–18%), and stearic acid (C18:0, 7–8%) were found in seeds. The reported review corroborated that though the oil extraction process from seeds has been optimized by various researchers using different approaches but a feasible method for continuous separation of seeds followed by efficient oil extraction method for maximum oil recovery is still demanding. The efforts for the use of mechanization techniques for seed separation followed by oil extraction on pilot scale need to be studied in detail.

Peel powder and pectin

Generally, dragon fruits are consumed fresh or being processed into juice. The fruit consists of 36.70% to 37.60% of peel which is normally discarded during processing, especially beverage processing industries which may create environmental problems.[42] Peel is a good source of pectin, phenols, antioxidants, betacyanin pigment, total dietary fibre, and hence, its conversion into easily handled products with a longer shelf life is required. It can also be utilized for extraction of the pigments from peel and used the extracted pigments into the other products to enhance its functional qualities.

Dragon peel powder (DPP) prepared using different methods are summarized in Table 7. Better retention of red colour was observed in spray drying as compared to drum drying of peel. Moreover, without prior addition of maltodextrin, spray-drying of pitaya peel powder cannot be obtained as it is helpful in reducing powder stickiness. Also, the use of maltodextrin can assist in the retention of betacyanin pigment and other functional properties.[76]

As per the Fifth A Schedule (Regulation 18 c) Table II of Food Act 1983 and Regulations Malaysia, dragon fruit peel powder can be claimed as a high total dietary fiber food, with minimum 6 g fiber/100 g solids. Hence, it can be used as a functional ingredient in different foods and beverages.[37]

Table 7. Preparation of dragon peel powder using different drying methods.

Drying method	Varieties used	Operating parameters	Obtained powder coloured	Findings	References
Drum drying	Red dragon fruit [*Hylocereus polyrhizus*]	• Drum speed: 1 rpm • Steam pressure: 2 bar • Drum gap: 0.1 mm	Purple colour	• Moisture content: 10.66% w.b. • Water activity: 0.420 • Betacyanin content: 80.21 mg/g of dm • L value: 37.32 ± 0.27 • a value: 13.56 ± 0.23 • b value: 0.97 ± 0.09 • Hue: 3.61 ± 0.32 • Chroma: 13.60 ± 0.31 • 98.62% retention of total phenolic content • 3.328 mg trolox/g dm of reduction of radical scavenging activity • Powder density: 0.1315 g/mL • Solubility: 51.44% • Water holding capacity: 2.523 g water/g sample • Oil holding capacity OHC: 3.57 g/g • Swelling capacity: 6.23 ml/g	[37]
Spray drying	Red pitaya fruits (*Hylocereus polyrhizus*]	• Inlet temperature: 149, 155, 165, 175, 181°C • Outlet air temperature: 72, 75, 80, 85, 88°C • Concentration of maltodextrin DE 10: 4, 8, 15, 22, 26% (w/w)	Purplish-red	• Optimized condition obtained: 165°C of inlet temperature, 80°C of outlet air temperature and 15% (w/w) of maltodextrin DE 10 • Powder contains 3.30% moisture content, 0.30 water activity, 87.62% betacyanin retention, 66.94 L value, 27.72 a value, 93.03% solubility:93.03%, 28.21% hygroscopicity	[76]
Spray drying	Red pitaya fruits (*Hylocereus polyrhizus*]	• Inlet temperature: 165°C • Outlet air temperature: 80°C • Concentration of maltodextrin DE 10: 15% (w/w) • Storage of powder in Low-density polyethylene bags at accelerated (45 ± 2°C; 38% RH) for 14 weeks and room temperature (26 ± 2°C, 50-70% RH for 6 months)		• Moisture content: 3.30% • Water activity: 0.299 • Betacyanin content: 64.66 mg/100 g • a value: 23.10 • Solubility: 89.83% • Hygroscopicity: 27.63% • Half-life of the powder was predicted to be approximately 76.2 weeks at accelerated temperature and for 38.3 months at room temperature. • More than 86% of retention of betacyanin pigment observed at both the storage temperatures	[77]

(*Continued*)

Table 7. (Continued).

Drying method	Varieties used	Operating parameters	Obtained powder coloured	Findings	References
Tray drying	*Hylocereus undatus*	• Peel of 6 × 2 cm strips • Forced air temperature: 50, 60, 70°C • Air speed: 1.0 m/s		• Increase in the drying temperature from 50°C to 70°C resulted in increase in pH (5.06 to 5.13), ascorbic acid (11.38 to 16.11 mg/100 g), luminosity (48.76 to 59.29), yellowness (17.80 to 28.99) and decrease in reducing sugars (8.56% to 5.56% glucose), moisture content (5.39% to 4.40% w.b.), water activity (0.353 to 0.318), titratable acidity (2.67% to 2.25% citric acid), betacyanins (51.81 to 17.25 mg/100 g), betaxanthins (63.50 to 35.22 mg/100 g) and redness (16.80 to 28.99). • Drying temperature of 50°C considered optimum because it retain maximum content of betacyanins and betaxanthins which helps industries to substitute artificial dyes as well as promote the health benefits.	[78]

Montoya-Arroyo et al.[79] in their study obtained fine powder from freeze-dried dragon fruit peel which was converted into alcohol insoluble residues and subjected for rheological measurements in aqueous solutions at various concentrations (1–10% w/v). The results confirmed that owing to low values of degree of esterification and pectin content, pitaya peel is not suitable for pectin extraction. However, shear thinning flow behavior and high viscosity at low concentrations indicated similarity to commercial thickeners available in market such as guar gum and lotus bean gum. De Mello et al.[46] through their experimental results showed that pitaya peel had strong gel behavior thermal stability during heating at various temperatures (5°C to 95°C) indicating it can be considered as a texture agent. Moreover, they suggested that dragon fruit peel can be utilized as a functional ingredient for food products due to its nutritional value, especially for the presence of high fiber content.

Among the different bakery products available in the markets, cookies or biscuits contribute major shares. Normally, these are prepared from refined flour, sugar, and hydrogenated fats with the addition of other additives and emulsifiers. To enhance its nutritional qualities an attempt was made by Ho and Abdul Latif[80] to add DPP as an ingredient that also has good antioxidant properties. For the preparation of cookies, refined flour was substituted with 5%, 10%, and 15% of DPP. It was observed that betacyanin of dragon peel contributes to a good reddish colour (5.10) of composite cookies, however, it receives less score than the control (5.73). Also, an increase in the DPP amount resulted in increased diameter and spread ratio without affecting the hardness of the crumb. Up to 15% addition of DPP was found to improve nutritional qualities without affecting the sensory acceptability of cookies.

Thirugnanasambandham and Sivakumar[81] extracted betalain from dragon fruit peel using microwave-assisted extraction (MAE). The optimum conditions used were microwave power (100 W), temperature (35°C), and treatment time (8 min) which resulted in 9 mg/L of betalain content from 20 g sample. Dragon fruit peel has a good source of bioactive compounds such as phenolic acid, flavonoids, and betalains which can be extracted from the MAE method.[82] On the similar line, extraction of polyphenols was done using the following conditions such as 20.3 min of extraction time, 33.4:1 mL:g of ratio of solvent to raw material, 497 W of microwave power, 43.3°C of extraction temperature, and 64.9% of ethanol concentration which resulted in the polyphenols yield of 463.8 ± 1.1 mg gallic acid equivalent per 100 g of dry dragon fruit peel.[82]

Conventionally, apple pomace, citrus albedo, and citrus peel are utilized as raw material for pectin production in the world.[83–85] The dragon fruit peel also contains a good amount of pectin (approx.17%) which is equivalent to apple pomace (10–15%) and slightly lesser than citrus peel (20–30%) on dry matter basis as reported by Tang et al.[86] Moreover, the amount of pectin in dragon peel is on the higher side than reported for many by-products of the food industry, i.e. sunflower head residues[87], peach pomace,[88] and cocoa husks.[89] Tang et al.[86] reported the highest yield of pectin at 120 min of extraction time, with pH 3.5 and ethanol ratio of 0.5. Also, Thirugnanasambandham et al.[90] emphasized that the MAE method was suitable for extraction of pectin from dragon fruit peel with maximum pectin yield of 7.5% using 400 W of power, 45°C of temperature, 20 min of extraction time, and 24 g/mL of solid–liquid ratio.

The reported literature corroborates that, pitaya peels have various bioactive, phenolic compounds and it can be utilized as a food additive ingredient for the preparation of bakery products. Use of spray and freeze drying has been adopted by researchers for the preparation of peel powder to protect the nutritional components, however, it also involves high operation cost. Hence, the feasibility of alternative novel or hybrid drying techniques has to be studied in reference to the cost-effective drying, focusing on the small growers and processors.

Conclusion

Dragon fruit is an emerging fruit crop in countries like India and the area of production is increasing nowadays. Although, at present the availability of fresh fruit is very seasonal and localized but the potential for domestic and international marketing is very high. Pitaya, owing to its nutritional and functional properties, can help in reducing the risk of chronic diseases. The demand for extracted colorants from natural sources like pitaya peel will be increasingly higher for future markets, whereby colouring foodstuff from pitaya will be a genuine option in contrast to red beet, which conveys negative implications due to its high nitrate and geosmin levels. This article reported the detailed information regarding the complete utilization of dragon fruit as well as its by-products for food processing and value addition applications. At present, derived processed products of pitaya rarely appear in the market and more research is required to improve their trading opportunities. Dragon fruit has been used for the preparation of different value-added products, nonetheless, there is a dispensable gap in promoting the products in the global market. Focus in this direction could be beneficial to make dragon fruit products available to the major population. Also, there is a need to focus on the mechanization in preparation of value-added dragon fruit products considering the ergonomic safety and throughput capacity, as for its preparation manual process has been adopted. The mechanization will help to reduce the production cost, human drudgery and in achieving a better quality of end products. Processing of by-products, i.e. peel and seed merely will not enhance the profitability, yet additionally provide new products for food, cosmetic, and pharmaceutical industry. Additional research is paramount until reliable and consistent information to investigate its unlimited use by the food, pharmaceutical, and cosmetic enterprises are accessible. Summarized, both industrial and developing countries will be extensively benefitted by effective pitaya processing.

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