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Impact of Extraction, Processing, Storage and Packaging Conditions on the Antioxidant Activity of Dragon Fruit (*Pithaya*) – A Review

Atyurmila Chakraborty,[a] Kavitha Jayaseelan,[a*] Sudip Kumar Mandal[b*]

[a]*SRM College of Pharmacy, SRM Institute of Science and Technology, Chengalpattu Dist. – 603203, Tamil Nadu, India.*

[b]*Dr. B. C. Roy College of Pharmacy and AHS, Durgapur-713206, West Bengal, India*

Abstract

The use of natural products as food is increasingly being used medicinally as a result of rising consumer demand. One such naturally occurring fruit from the Cactaceae family is called "Dragon fruit," and its exceptional antioxidant properties have helped it gain increasing notoriety in recent years. Antioxidants are compounds that can delay, slow down, or even completely prevent food from developing rancidity or other oxidative flavor deterioration. The dragon fruit possess significant nutritional value due to the abundance of antioxidants such as phenolic acids, flavonoids, and betalain, present in its pulp, peel, seeds, and leaves. Antioxidants become a significant component to retain preservation technology and modern therapeutic applications of dragon fruit. The objective of this study is to collect information on the antioxidant activity of dragon fruit during each stage of processing, including extraction, *in vitro* and *in vivo* models used to estimate antioxidants, drying, thermal treatment & color effect, storage, transportation, and packaging. It is evident that peels exhibit the maximum degree of antioxidant activity and the DPPH assay is the most popularly used *in vitro* model. The recommended storage temperature for maximizing shelf life is 5°C, whereas contemporary extraction techniques like UAE and MAE exhibit enhanced antioxidant activity.

Keywords: Dragon fruit; Antioxidant activity; Extraction; Processing; Thermal treatment; Storage; Transportation; Packaging

1. Introduction

The biggest invention ever made by God is a natural product. Nowadays, the terms "food" and "natural products" are used interchangeably. The use of natural products as food is very common, and they can also be manufactured to satisfy consumer demand [1]. Several new diseases, as well as epidemics of existing diseases such as cancer and infectious diseases, have emerged in the last century. There is a move toward using natural products because of their lack of side effects and low cost. Along with allopathic medicines, natural products have been used as first-line therapies, dietary supplements, and adjuvants in therapeutics. These days, natural product research for therapeutic purposes is thriving [2-5].

"Dragon fruit" is one such natural fruit that has gained popularity in recent decades. Dragon fruit, also known as pitaya or pitahaya, is a member of the Cactaceae family. Commercially, the species in both genera (*Hylocereus* and *Selenicereus*) are grown, but the *Hylocereus* genus is more common, with around 16 different species [6] Fruits are oval in shape [7] and vary in size depending on the species from small (100–250 g) to large (200–800 g) [8-9]. It has a stunning appealing colour, smooth pulp that melts in the mouth, edible seeds of a dark brown colour embedded in the pulp with sweet and sour taste, and is incredibly nutritive [10-11]. This eye catching attractive fruit can also be known as Strawberry Pear, Night blooming Cereus, Belle of the night, Conderella plant and Jesus in the Cradle. Pitaya, which means "the scaly fruit," is the name given to it because of its "scaly surface" [12]. The majorities of pitaya species are found in Mesoamerica, where they grow in a variety of habitats ranging from a few meters to 1700 meters above sea level and receive 500 to 2000 mm of rainfall [13]. Fruit is grown all over the world because of its excellent drought resistance power, ease of adaptation to high light and temperature levels, wide range of tolerance to various soil salinities, and advantages to human health [14-17]. More than 20 tropical and subtropical nations, including the Bahamas, Colombia, Vietnam,

*Corresponding authors e-mail: kavithaj@srmist.edu.in
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Bangladesh, West Indies, etc. commercially cultivate it [16]. Dragon fruit production spans nearly 40,000 ha in Vietnam, the world's top exporter, with an annual production volume of about 1 million metric tones (MT) [18]. In China, after lychee, longan, banana, and mango, dragon fruit is the fifth most popular tropical fruit imported from Asia [19]. One hectare of this crop can support about 800 dragon fruit plants, and once planted, it will continue to grow about 20 years and this is the best part of dragon fruit cultivation. Different varieties of the fruit are *Hylocereus undatus*, *Hylocereus polyrhizus*, and *Hylocereus (Selenicerus) megalanthus* each with leathery, slightly leafy skin come in different beautiful colors. **Table 1** enlisted various dragon fruit varieties in terms of its characteristics and cultivation [20].

Dragon fruit has both nutraceutical and therapeutic benefits. The term "functional foods" refers to natural products that contain bioactive phytoconstituents and can be used to develop nutraceutical formulations. Dragon fruit can be referred to as both “functional food” and “fruit crop for future”. Although it is eaten as food, the existence of dragon fruit among humans is not solely dependent on the consumption of the fruit in its raw or juice form. Numerous diseases can be treated with dragon fruit as it is an excellent antioxidant [21-22]. According to medical research, dragon fruit has beneficial anti-inflammatory, anti-diabetic, anti-cancer due to the presence of potent antioxidants [23]. In addition to antioxidants, vitamins, carbohydrates, and fibre, it also contains betacyanin [23-24],one of the typical components of dragon fruit that gives the flesh its colour [25]. Phenolic compounds and betacyanin are the main component responsible for antioxidant activity [22, 26]. Previously published literature on dragon fruit covers botany, biology, cultivation, phytochemical constituents, pharmacological activities, processing, by-product utilization, waste utilization, and pest and disease control. However, there is a notable absence of a comprehensive systematic review in the existing literature that explores many techniques employed to assess the impact of antioxidant activity on the processes of extraction, drying, temperature control, storage, packaging, and transportation of dragon fruit. Consequently, the existing data has been gathered and presented in this comprehensive analysis, highlighting the efficacy of dragon fruit as an antioxidant starting from its processing to transportation.

Table 1 Comparison of dragon fruit varieties in terms of its cultivation

Description	*Hylocereus undatus* (White dragon fruit)	*Hylocereus polyrhizus* (Red dragon fruit)	*Selenicereus megalanthus* (Yellow dragon fruit)
Flower characteristics	• Large oblong • Pink-skinned fruit with white flesh	• Large oblong • Red-skinned fruit with red flesh	• Medium oblong • Yellow-skinned fruit with white flesh
Flavor	Semisweet, good	Semisweet, good	Sweet, very good flavour
Vegetation season	Summer	Summer	Winter
Storage	10 °C	10 °C	6 °C
Drought resistant	Yes	Yes	Yes
Recommendation for planting in the home landscape	Yes	No	Yes

2- Nutritional value and medicinal uses

Dragon fruit is a multifunctional fruit as each and every part of dragon fruit has shown effective pharmacological activities. The presence of numerous active phytoconstituents such as betalains, flavonoids, polyphenols, terpenoids, steroids, saponins, alkaloids, tannins, and carotenoid is the reason for these multiple pharmacological activities [25, 27-29]. Dragon fruit has antioxidant, anti-inflammatory, anti-diabetic, antibacterial, hepatoprotective, anticancer, and wound healing properties. Because of the presence of betalains, it is an excellent natural colorant. Each component of the dragon fruit, including the pulp, peel, seeds, flower buds, and dried flowers, contains nutrients with high nutritional value, including antioxidants, fibre, vitamin C, minerals, particularly calcium and phosphorus, moisture, protein, fat, and crude fibre [30]. The flowers and young stems of dragon fruit can be consumed as a vegetable or made into an antioxidant-rich tea [13] while the dried ones are used to make homemade medicines, seeds have a laxative effect, fruit has been shown to help with gastritis, and the stalk can be used to help with kidney problems [31]. The pulp of dragon fruit has been used to make value-added products such as juice, jam, jelly, powder, wine, and so on. Dragon fruit peels are not considered as waste because they have been shown to have higher nutritional values than their edible portion [32]. Peel can be used to extract natural food colorants and as a source of pectin. Dragon fruit has traditionally been consumed, which is why people are becoming more interested in growing dragon fruit in their backyard gardens [33]. **Table 2** lists the various varieties, parts used, phytoconstituents, and pharmacological use of dragon fruit.

The aforementioned table makes it abundantly clear that all dragon fruit varieties have indicated potent antioxidant activity. There has been an increase in the use of natural antioxidant substrates found in medicinal plants that have protective effects against the cellular damage caused by free radicals, which is a factor in many diseases like cancer [52]. The powerful antioxidant properties of dragon fruit make it a potent anti-inflammatory, antidiabetic, anti-cancer and many other disease treating ailments.

Fig. 1 represents different activities of dragon fruit being a potent antioxidant.

Fig. 1. Different activities of dragon fruit being a potent antioxidant

3. Dragon fruit and antioxidant activity

3.1. In vitro and In vivo Models Determining Antioxidant Activity

The dragon fruit has many health advantages for people because of its nutritional and therapeutic qualities, especially for managing and controlling oxidative stress. Oxidative stress can be defined as a difference between the generation of free radicals and reactive metabolites, commonly referred to as oxidants or reactive oxygen species (ROS), and their elimination by antioxidant mechanisms [53]. The human body contains antioxidants such as catalase, glutathione, and superoxide dismutase to protect our bodies from oxidative stress caused by ROS [54]. By eliminating free radicals at the cellular level, an efficient antioxidant can reduce oxidative stress [55]. However, when the antioxidants are unable to counteract this excessive oxidative stress, all of the essential cellular components—including DNA, proteins, and membrane lipids can be compromised, which may eventually result in abnormal DNA linkages and carcinogenesis or cell death [56-59].

Antioxidants possess two distinct mechanisms through which they can impede or postpone oxidation. The first mechanism involves the interruption of the chain reaction and the elimination of free radicals, leading to the classification of the compound as a primary antioxidant. The second mechanism, known as the secondary or preventive mechanism, operates independently of direct free radical scavenging. Secondary antioxidants work in a number of different ways, such as by attaching to metal ions, scavenging reactive oxygen species, turning hydro peroxides into non-radical species, absorbing UV radiation, or inactivating singlet oxygen [60]. The antioxidants that exhibit various pharmacological effects include a variety of active phytoconstituents like flavonoids, polyphenols, alkaloids, tannins, and carotenoids. As antioxidants, flavonoids may operate in a direct or indirect manner. To counteract the harmful effects of free radicals, a direct mechanism is used to donate hydrogen ions [61]. By interacting with the reactive component of the radical, it stabilizes the reactive oxygen species. Radicals are rendered inactive due to the strong reactivity of the hydroxyl group in flavonoids. The chain-breaking antioxidants preferentially interact with radicals via proton-coupled electron transfer (PCET) or single electron transfer (SET) [62]. Mechanism of action of various phytoconstituents responsible for showing antioxidant activity of dragon fruit has been depicted in **Fig. 2.**

Table 2: Different varieties, parts used, phytoconstituents and uses of dragon fruit

Varieties of dragon fruit	Parts used	Phytoconstituents	Pharmacological Uses
Hylocereus undatus (White dragon fruit)	Flesh	Carbohydrate, protein, amino acid, tannins, flavonoids, steroids, alkaloid [29]	Antimicrobial activity[34], Antidiabetic activity[35], Anti-inflammatory activity, Antioxidant activity[21].
	Peel	Phenolics[36]	Antimicrobial activity[37] , Antioxidant activity, Anti-inflammatory activity[21]
	Seed	Phenolics[36], essential fatty acid like linoleic acid, linolenic acid , other fatty acid like cis-vaccenic acid, palmitic acid and oleic acid [38]	Antioxidant activity, hepatoprotective activity[39]
	Stem	Raw protein, raw fibre and several minerals such as P, K, Ca, Mg, Na, Fe, Zn [33]	Edible as vegetables, dried stems used as homemade medicine [40]
	Flower	Phenolic and flavonoid content[41]	Wound healing properties[41]
Hylocereus polyrhizus (Red dragon fruit)	Flesh	Betacyanine, phenolics, flavonoids[42]	Antioxidant activity[43], Anticancer activity[44], Antithrombotic activity[45], Natural food colorant[6]
	Peel	Betacyanine, phenolics, flavonoids[42]	Antioxidant activity [21], Antimicrobial activity[37] , Wound healing properties[41], Antidiabetic activity[46],

			Antiulcer activity[47]
	Seed	Phenolics, essential fatty acid	Natural Antioxidant[48]
	Stem	Raw protein, raw fibre and several minerals such as P, K, Ca, Mg, Na, Fe, Zn[34]	Anticancer activity, Antimicrobial activity, Antioxidant activity, Wound healing properties[49]
	Flower	Phenolic and flavonoid content[45]	Wound healing properties[50]
Selenicereus megalanthus (Yellow dragon fruit)	Peels	Phenolic compounds like Coumaroylquinic acid, feruloylquinic acid, diferulic acid and their derivatives[51]	Antiinflammatory activity[51]

The assessment of antioxidant activity for unknown molecules, compounds, or plants mostly relies on two basic models: in vitro models and in vivo models. In order to assess the efficacy of natural antioxidants, whether in their pure form or as extracts derived from plants, an extensive number of in vitro methodologies have been devised. The ABTS radical scavenging method, FRAP test, and Diphenyl-picryl-hydrazyl Radical Scavenging (DPPH) test, in addition to the assessment of Total Phenolic Content (TPC) and Total Flavonoid Content (TFC), are the principal in vitro techniques employed for evaluating the antioxidant components in dragon fruit. The Total Phenolic Content (TPC) is utilized to quantify the concentration of phenolic compounds present in the samples. Phenolic compounds present in plants possess redox characteristics, which enable them to function as antioxidants. The most popular technique among them all for manually analyzing antioxidant contents is the DPPH assay because it is very straightforward, quick, and affordable. The methodology described in this study is suitable for analyzing both solid and liquid samples, and it is not restricted to the assessment of a specific antioxidant but may be used to determine the overall antioxidant capacity of the sample [63]. FRAP and ORAC are sometimes preferred in combination with the DPPH assay because they can more accurately represent the antioxidant properties. In DPPH test the stable 2, 2-diphenyl-1- picrylhydrazyl free radical reacts with hydrogen donors [64-65] and produce purple colour with the maximum absorbance of 517 nm. The decolorization of the compound occurs when antioxidants interact with DPPH, resulting in the reduction of the stable free radical [66].

The ABTS test, alternatively referred to as the Trolox Equivalent Antioxidant Capacity (TEAC) test, is utilized to evaluate antioxidant activity as instead of antioxidant concentration. This approach accounts for the presence of biologically inactive antioxidants [67-68]. The ABTS assay enables the quantification of antioxidant activity in complex combinations of chemicals, facilitating the distinction between additive and synergistic effects [69-70]. The ABTS decolorization assay can be employed to assess the presence of hydrophilic and lipophilic antioxidants. The reduction of the blue-green chromophore ABTS•+ (2,2-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid)) to ABTS occurs upon the addition of an antioxidant, leading to a decrease in color intensity. This reduction process can be quantitatively analyzed using a diode-array spectrophotometer. The FRAP method is utilized to evaluate the efficacy of antioxidants in reducing the complex of ferric iron and 2,3,5-triphenyl-1,3,4-triaza-2-azoniacyclopenta-1,4-diene chloride (TPTZ) to the ferrous form. This reduction process results in the formation of a highly pigmented Fe2+-TPTZ complex, which exhibits an absorption peak at a low pH of 3.6. A diode-array spectrophotometer is used to measure the change in absorption at 593 nm [71]. The amount of antioxidants present influences how much absorbance decreases [72]. The test in consideration is known for its rapidity and utility in conducting routine analyses [73]. **Table 3** lists the *in vitro* techniques for evaluating the antioxidant activity of various dragon species.

In case of *in vivo* method, for evaluating the antioxidant activity of unidentified compounds from organs like the kidney and liver of laboratory animals, they are kept in accordance with the ethical standards for the care and use of animals. To combat ROS and safeguard the redox homeostasis of the cell, cells are equipped with a variety of mechanisms. natural antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), malondialdehyde (MDA), and glutathione peroxidase (GPx), for instance, play crucial roles in neutralizing free radicals and preventing cell damage [74]. The animals are typically sacrificed after a predetermined amount of time and their blood or tissues are used for the test. MDA is a colorimetric indicator of lipid peroxidation and free radical generation that can be measured using thiobarbituric acid reactive substance (TBARS). Budi et al. showed the impact of red dragon fruit (*Hylocereus polyrhizus*) peel extract on the reduction of MDA levels in gingival tissue in chronic periodontitis rats [75]. Lipid peroxidation and malondialdehyde (MDA), which are the byproducts of lipid peroxidation and are frequently used as indicators of oxidative stress, are frequently used criteria in assessing oxidative damage associated with chronic periodontitis [76-77]. According to this study, red *Hylocereus polyrhizus* provision peel extract can reduce MDA levels in rats with chronic periodontitis. Gums and periodontal tissue health can be improved in public by consuming dragon fruit regularly.

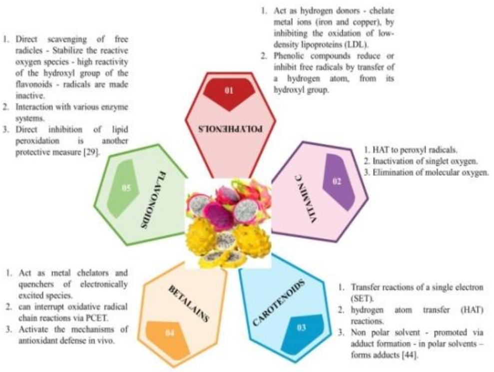

Fig. 2. Mechanism of action of important constituents responsible for showing antioxidant activity of dragon fruit

3.2. Impact of extraction on antioxidant activity

Extraction is considered one of the primary methods for isolating total phenolic compounds (TPC) from plant sources. The efficacy of the extraction process is influenced by several factors, including the chemical composition of the plant materials, the methodology employed for extraction, the particle size of the sample, the choice of solvents, and the potential presence of interfering chemicals [78]. The polarity of the solvent, pH, temperature, extraction time, and chemical nature of the sample all affect the percentage yield of the extraction [79]. Techniques for sample preparation and extraction are extremely important in antioxidant studies because they can affect how many antioxidant compounds are recovered from the active constituent and how the extracted substances' physiological properties are affected.

Researchers have used a variety of extraction methods, including traditional methods like maceration and reflux as well as novel methods like microwave assisted extraction (MAE), enzymatic extraction, and ultrasound-assisted extraction (UAE) [80-82] that will increase the extraction efficiency, to determine the antioxidant components and their capacity in various dragon fruit varieties. Traditional extraction techniques, which are frequently employed in research, necessitate high temperatures; longer extraction times, and consequently leads to the degradation of heat-sensitive bioactive compounds. Contrarily, UAE can be applied commercially and is very straightforward and affordable [83-84], allowing greater surface area contact between the sample and solvent [85]. One significant and ecologically conscious extraction technique is MAE, which offers the advantages of enhanced repeatability within a shorter timeframe, simplified handling procedures, minimized solvent usage, and decreased energy requirements, all while maintaining the extraction yield of the desired compounds [86].

Nowadays, optimizing process variables in extraction processes such as temperature, sample mass, and extraction time may improve treatment efficiency while also providing a novel opportunity to learn the mechanism behind extraction technique [87]. In order to obtain useful and statistically significant models of a phenomenon with the least amount of experiments possible, statistical design of experiments is a helpful technique. One statistical tool, called response surface methodology (RSM), is used to model and investigate multivariable systems in which a particular response is affected by a number of different variables. The procedure can be completed faster and with less energy consumption kudos to the optimized parameters, which also lower elevated temperatures and prevent solvent waste at high solvent-solid ratios. Additionally, it aids in selecting the best antioxidant activity method that is feasible or exhibits an enhanced response with ideal parameters. Box Behnken design (BBD) is the most popular design used with RSM; it is effective and versatile, providing enough information on the effects of variables and overall experiment error with a minimal number of experiments [88-89]. As a result, using the RSM will increase the extraction of antioxidant compounds and guarantee that the best result in terms of antioxidant activity is obtained.

Thirugnanasambandham and hamand Sivakumar used RSM and BBD to optimize the operating parameters in the MAE, such as temperature, sample mass, and extraction time, on the betalain content from dragon fruit peel, and antioxidant activity was determined using the DPPH assay. As extract concentrations rise, betalains' antioxidant activity also rises. This outcome shows how effective the MAE process is as a potent extraction method with a fast extraction time [90]. Ramli et al. demonstrated through a comparison of the conventional method and the UAE method that the choice of extraction method depends on the fruit part being extracted. According to the study's findings, red dragon fruit peel flavonoid content and scavenging activity increase while extraction yield is significantly decreased by UAE. On the other hand, UAE boosts the amount of red dragon fruit flesh that can be extracted while lowering the amount of total flavonoids present and the scavenging activity [25]. According to research by Luo et al, supercritical carbon dioxide extraction increases the amount of polyphenols that are responsible for antioxidant activity in the peel extract of the plants *Hylocereus polyrhizus* and *Hylocereus undatus*. These polyphenols are then analyzed by gas chromatography-mass spectrometry (GC-MS). In conclusion, triterpenoids and steroids constituted the majority of the compounds in *Hylocereus* polyrhizus and *Hylocereus undatus*. In contrast, the *Hylocereus polyrhizus* supercritical carbon dioxide extract had a higher content of triterpenoids whereas the *Hylocereus undatus* extract had a higher content of steroids. It can be seen that various elements, including geographic, climatic, seasonal, and experimental conditions, typically have an impact on the two extracts' chemical composition [44]. By using the foliage and peels of *Hylocereus undatus*, Som et al. demonstrated a comparative study on antioxidant activity using DPPH assay. The extractions were conducted using a maceration method with chloroform and methanol solvents, and the peels contained higher antioxidants than the foliage in the chloroform solvent and vice versa for the methanol solvent [36]. Pectin from the peels of the dragon fruit (*Hylocereus polyrhizus*) was extracted and characterized by Zaidel et al. In order to have high pectin yields without sacrificing quality, it is crucial to choose an appropriate extraction condition based on the chemical characteristics of pectin and its properties. Pectins are intricate carbohydrate molecules that are employed in a variety of food products as a gelling agent, thickener, stabilizer, and emulsifier. Pectin is extracted under various conditions from different sources. The nature of the raw material and the economics of the extraction process influence the extraction conditions. Using distilled water at 80 °C and different extraction times of 20, 40, 60, and 80 minutes, the peels of the dragon fruit were removed using the hot water extraction method and antioxidant activity was evaluated using the DPPH assay. According to the findings, the yield of pectin decreases (20.34 to 16.20%) as the time of the extraction process increases. With an increase in extract concentration, the antioxidant activity rises [91]. The above mentioned studies on dragon fruit are really impressive as they are using novel techniques along with optimizing the process variables to improve the extraction efficiency, the quality and quantity of active bio constituents for the sake of increasing antioxidant activity. **Table 3** enlisted various extraction procedure, parts of the plant used, solvent used, models of antioxidant study and inference of various studies determining antioxidant activity and proportion of methods reported on the estimation of antioxidant activity in different parts of dragon fruit has been represented in **Fig. 3**.

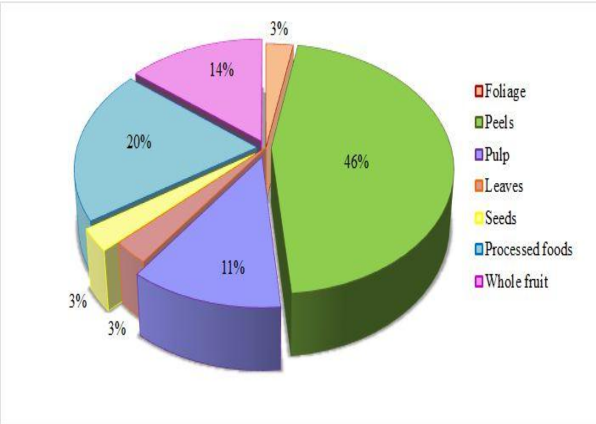

Fig. 3. Proportion of methods reported on the estimation of antioxidant activity in diffrent parts of dragon fruit

Table 3 : *In vitro* method determining the antioxidant activity of dragon fruit

S.No.	Species of dragon fruit	Parts of the plant	Extraction techniques employed	Solvent used	Models used	Inference	Ref.

		used					
1.	*Hylocereus undatus*	Foliage and peels	Maceration	Chloroform ($CHCl_3$) and Methanol (Meth)	• DPPH free radical scavenging activity • TPC	• Meth solvent has high TPC for both foliage and peels compared to $CHCl_3$ solvent. • Due to a lower percentage of free radical scavenging activity in peels than in foliage, peels have higher antioxidant content in $CHCl_3$ solvent than foliage. Peels in meth solution have lesser antioxidant activity than foliage.	[36]
2.	*Hylocereus undatus, Hylocereus polyrhizus, Hylocereus costaricensis*	Peel	Reflux	n-hexane, ethyl acetate (EA), ethanol(Eth)	• DPPH scavenging assay • ABTS scavenging assay • TPC • Total flavonoid • content(TFC) • Total carotenoid content(TCC)	Except for the n-hexane peel extract of *Hylocereus polyrhizus*, every dragon fruit peel extract exhibited significant antioxidant activity.	[92]
3.	*Hylocereus polyrhizus*	Peel	Maceration	Pigment extraction-Eth 80% and	• DPPH scavenging assay	Pigment extract showed the highest antioxidant activity compared to EA,	[93]

				0.1 N HCl and then partitioned with n-hexane, dichloromethane, EA Non pigment extraction- Meth and then partitioned with n-hexane, dichloromethane, EA		dichloromethane, and n-hexane. The antioxidant activity in pigment extracts might be due the present of betalains or phenolic compounds.	
4.	*Hylocereus undatus*	Farmented and nonfarmentedfreeze dry juice samples	NA	Distilled water	• DPPH scavenging assay • FRAP assay	According to the outcomes of the DPPH and FRAP experiments, the dragon fruit juice fermented with L. plantarum in this investigation had marginally greater activity compared to fresh juice. The study's findings showed that fermented dragon fruit juice has a lot of promise for use in the manufacturing of functional drinks with increased biological	[94]

						activity and shelf life.	
5.	*Hylocereus undatus* *Hylocereus polyrhizus*	Peel and seed	NA	Meth	• DPPH scavenging assay • ABTS scavenging assay • FRAP assay • TPC	The phenolic compounds discovered in dragon fruit peel utilising UPLC-QTOF-MS/MS analysis were isorhamnetin glycoside and isorhamnetin glucorhamnoside.	[95]
6.	*Hylocerecus polyrhizus*	colorant powder from dragon fruit peels	NA	deionized water	• DPPH scavenging assay • ABTS scavenging assay • FRAP assay • TPC	The antioxidant activity of the colourant in the DPPH assay was lower than that of the standard ascorbic acid. In the ABTS experiment, the colorant's antioxidant activity was likewise noticeably lower than that of the extract and standard. These findings all pointed to the possibility of using dragon fruit peel extract and its colourant powder as a secure replacement for artificial food colouring and a good source of natural pigment with antioxidant characteristics.	[96]
7.	*Hylocereus undatus*	Fruit		distilled water,	• DPPH scavenging	Fruits displayed varying degrees of antioxidant activity. As	[97]

				acetone, EA, Meth and Eth	assay	concentration enhanced, the antioxidant activity also enhanced. The presence of phenols, alkaloids, terpenoids, saponin, flavonoids, steroids, tannins, carbohydrates, proteins, amino acids, and carotenoids in various solvent extracts of dragon fruit is confirmed by qualitative tests.	
8.	*Hylocerecus polyrhizus*	Extracted pectin from peels	20, 40, 60 and 80 min Hot water extraction	Distilled water	• DPPH scavenging assay	The sample with a 60-minute extraction time had the highest antioxidant activity, while one with a 20-minute extraction time had the lowest. The extract's capacity to neutralise free radicals was somewhat lower than that of ascorbic acid. 40 µg/mL of pectin extracted for 60 minutes demonstrated the best antioxidant activity.	[91]
9.	*Hylocereus undatus* *Hylocereus polyrhizus*	Leaves	Maceration	Meth	• DPPH scavenging assay • TPC	Due to the increased TPC of red dragon fruit leaves compared to white dragon fruit leaves, the antioxidant activity of red dragon fruit leaf extract is higher than white dragon fruit leaf extract.	[98]

						Ascorbic acid has a high level of antioxidant activity, but red dragon fruit leaf extract and white dragon fruit leaf extract have a moderate level of antioxidant activity.	
10.	*Hylocereus undatus Hylocereus polyrhizus*	Peel	Supercritical carbon dioxide extraction	Eth	• DPPH scavenging assay	Supercritical carbon dioxide extracts of pitaya (*H. polyrhizus* and *H. undatus*) peel could be a source of potential antioxidantcompounds.	[44]
11.	*Hylocereus polyrhizus*	Fresh juice from fruit pulp		Water	• DPPH scavenging assay • TPC • TFC • ABTS scavenging assay • FRAP assay • Phosphomolybdate assay	Water extract of pulp *of H. polyrhizus* possesses considerable antioxidant activities and capacities. Extraction of beneficial bioactive compounds in plant using water as a solvent has a promising future in the pharmaceutical and nutraceutical industries.	[43]
12.	*Hylocereus undatus Hylocereus polyrhizus*	Fruit	Maceration	Meth	• DPPH scavenging assay	Red dragon fruits showed better antioxidant activity than compare to the white dragon fruits. However, the standard ascorbic acid showed better antioxidant activity than both the extracts.	[99]

13.	*Hylocereus polyrhizus*	Pulp and peel	Conventional extraction and Ultra sound assisted extraction (UAE)	Distilled water	• ABTS scavenging assay • FRAP assay • TPC • TFC	UAE substantially lowers the extraction yield while raising the flavonoid concentration and scavenging activity in the red dragon fruit peel, and vice versa for the pulp. This paper provides scientific support for the use of UAE for red dragon fruit peel in applied research and the food processing industry.	[25]
14.	*Hylocereus undatus* *Hylocereus polyrhizus* *Selenicereus megalanthus*	Fruit	NA	Meth and Water	• DPPH scavenging assay	In comparison to methanol extracts, total polyphenol levels were up to 1.2 times greater in water. The antioxidant content of the fruits can be used to monitor the quality of different dragon fruit varieties and to highlight the fruits' potential for a variety of uses.	[100]
15.	*Hylocereus undatus* *Hylocereus polyrhizus*	fruits (peels and pulps) and pulps	NA	Eth	• DPPH scavenging assay • TPC	The fruit (peel and pulp) of H. *polyrhizus* is followed by fruit (peel and pulp) of *H. undatus* in the hierarchy of free radical scavenging activity.	[21]
16.	*Hylocereus*	Pulp			• DPPH	White pulped fruits are superiors	[101]

	undatus *Hylocereus polyrhizus*				scavenging assay • ABTS scavenging assay • FRAP assay • CUPRAC assay • TPC • TFC	in terms of yield and sugar content, while red pulped fruits are better for phenolics with high antioxidant potential.	
17.	*Hylocereus polyrhizus*	dried dragon fruit peel powder containin g betalain	Microwave assisted extraction (MAE)	Distilled water	• DPPH scavenging assay	As extract concentrations rise, betalains' antioxidant activity also rises. In order to optimise the process variables for the MIE process for the extraction of betalain from dragon fruit peel, three factors—BBD and RSM—were used in this work. This result demonstrates the efficiency of the MAE procedure as a potent extraction method with a quick extraction time.	[90]
18.	*Hylocereus undatus*	water soluble polysach haride extracted from	UAE	Meth	• DPPH scavenging assay • Hydroxyl radical scavenging	From the peel of a dragon fruit, a novel water soluble polysaccharide known as DFPWSP-1 was isolated, purified, and subjected to chemical analysis.	[102]

		peels			activity • Superoxide anion scavenging activity.	Additionally, the polysaccharide DFPWSP-1 demonstrated a high DPPH radical, superoxide anion, and hydroxyl radical scavenging action. In the food industry, DFPWSP-1 might have potential as a natural antioxidant.	
19.	*Hylocereus undatus Hylocereus polyrhizus*	peel and pulp		80 % Eth	• DPPH scavenging assay • TPC • TFC • ABTS scavenging assay • Total Antioxidant Capacity (TAC)	According to the findings, the peel of the dragon fruit had more flavonoids and tannins than the pulp, which had a lower level of total phenolics and a weaker antioxidant potential. The measurement using HPLC-PDA revealed that the peel of dragon fruit contains higher concentrations of the majority of the chosen phenolic compounds, although the pattern of phenolic content differs between the pulp and peel. For the purpose of separating and characterizing the phenolic compounds in dragon fruit, the LC-ESI-QTOF-MS/MS technology was successfully used.	[103]
20.	*Hylocereus*	Powdere	Maceration	n-Hexane,	• DPPH	For food and cosmetic	[23]

	polyrhizus	d peel		Eth, and deionized water	scavenging assay • ABTS scavenging assay • FRAP assay • TPC	decorations, dragon fruit peel's modest antioxidant activity makes it a viable source of red and purple colour. Better antioxidant activity was consistent with the active ingredient; more phenolics were present in water than Eth.	
21.	*Hylocereus polyrhizus*	Fruit juice containing betacyanine	ultrasound-assisted enzymatic treatment	NA	• DPPH scavenging assay • FRAP assay • TPC	Liquid chromatographic and mass spectrometric (LC-MS) analysis and antioxidant tests by DPPH and FRAP assays verified that the optimization of ultrasound-assisted enzymatic treatment process toward betacyanin could improve the release of native betacyanins and betalain-related compounds.	[104]
22.	*Hylocereus undatus*	gold NPs by using dragon fruit		Distilled water	• DPPH scavenging assay • TPC	The biosynthesized AuNPs showed much higher antioxidant activity compared to The Hylocereus undatus fruit extract alone.	[105]
23.	*Hylocereus polyrhizus*	Peel	Maceration	70% Eth	• FRAP assay	At a concentration of 50 ug/ml, red dragon fruit peel extract exhibited the strongest FRAP antioxidant activity. The collagenase inhibition and	[106]

						FRAP activity of the kaempferol -3-O-rutinoside compound are greater than those of the red dragon fruit peel extract.	
24.	*Hylocereus polyrhizus*	fermented liquid dragon fruit - without pasteurization sample A (SA) and with pasteurization sample B (SB)	NA	NA	• ABTS assay • TPC • TFC • TFA (total flavanol assay)	Comparing SB to SA, it was found that SB had much larger levels of phytosterols (campesterol, stigmasterol, and β-sitosterol), betacyanins(betanin, isobetanin), acetic acids, TPC, TFC, and TFA, as well as a stronger potential to scavenge free radicals.	[107]
25.	*Hylocereus polyrhizus*	Betacyanin pigment from pulp		96% Eth	• DPPH scavenging assay • TPC • Vanillin-HCl assay	The dragon fruit represent a significant source of antioxidants which is a value added characteristic to any food crop.	[108]
26.	*Hylocereus undatus*	Peel pectin	Conventional extraction(CE) and UAE	Distilled water	• DPPH scavenging assay • ABTS assay	For the extraction of pectin from dragon fruit peel, UAE was a novel technology with high efficiency, time savings, and low	[109]

						energy consumption. When extracted under the same conditions, the antioxidant activity of DFP pectin by UAE was higher than that of DFP pectin by CE.	
27.	*Hylocereus polyrhizus Hisbiscus sabdariffa* L.(Rosella)	roselle and dragon fruit peel functional drink	Extraction temperature of (60, 80, and 100 ˚C) for the desired time (5, 15, and 25 min) has been used	Distilled water	• DPPH scavenging assay • TPC	The highest antioxidant activity is at a temperature of 100˚C with an extraction time of 25 minutes. Extraction temperature and time are one of the factors that can influence the stability of antioxidants.	[110]
28.	*Hylocereus undatus Hylocereus polyrhizus*	Dragon fruits-yogurt preparation	NA	NA	• DPPH scavenging assay • TPC	White dragon fruit enriched yogurts showed higher increment in total phenolic content than red dragon fruit enriched yogurts.	[111]
29.	*Hylocereus undatus Hylocereus polyrhizus*	Peel		50% Eth	• DPPH scavenging assay	For assessing the antioxidant capacity of fruits that react with DPPH solution, ESR spectroscopy may be more appropriate. Thus, in the food sector, this can be employed to maintain the antioxidant characteristics of	[112]

						fruits.	
30.	*Hylocereus undatus* *Actinidia deliciosa* (kiwi fruit)	Fruit	NA	Distilled water, Meth,Eth	• TPC • DPPH scavenging assay	The highest potent antioxidant content was found in Eth extract, followed by Meth and water. When compared to Actinidia deliciosa, *Hylocereus* undatus extract showed low antioxidant activity and free radical scavenging activity.	[113]
31.	*Hylocereus undatus* *Hylocereus polyrhizus*	Puree	NA	80% acetone	• TPC • TFC • DPPH scavenging assay • FRAP assay	When compared to white dragon fruit, the unheated red dragon fruit had double the TPC and antioxidative characteristics (FRAP and DPPH).	[114]

CE-Capillary Electrophoresis, TPC-Total Phenolic Content, TFC-Total Flavonoid Content, TFA-Total Flavanol Assay, UAE-Ultrasound assisted extraction, ABTS-2,2-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid, BBD-Box benhken design, $CHCl_3$ -Chloroform, DPPH-Diphenyl-picryl-hydrazyl, Eth-Ethanol, EA-Ethyl acetate, FRAP-Ferric Reducing Power Assay, FBD-Fluidized bed dryer, MAE- Microwave assisted extraction, Meth-Methanol, ORAC -Oxygen radical absorbance capacity, RSM-Response surface Methodology, TEAC-Trolox Equivalent Antioxidant Capacity , LC-MS-Liquid chromatographic mass spectrometry, NA – Not Available.

3.3. Impact of drying and thermal treatment on antioxidant activity

Fruits seem to contain polyphenolic compounds for a variety of reasons, including colour, antimicrobial activity, and antioxidant defense. In contrast to non-betalainic phenolic compounds; betalains, the coloured pigment found in dragon fruit peels, play a significant antioxidant role that is crucial [115]. A key commercial characteristic that influences acceptance and is taken into account as a visible quality control indicator for processed foods is colour [116-117]. However, the antioxidant activity, bioactive compounds, and colour of the compound are all impacted by thermal processing and drying times. The inactivation of microorganisms during thermal processing, also known as sterilization (high temperature and short time) and pasteurization (low temperature and longtime), is a crucial step in fruit preservation and shelf life extension. Alternatively, in various fruits and vegetables heat treatment increases the bioavailability of antioxidants [118-119]. To develop novel procedures for the manufacturing of safe food items with the greatest possible nutritional profile retention, it is essential to investigate thermal processing. Drying is a widely used approach for food preservation because it lowers postharvest losses and is a practical and affordable option [120]. By lowering the humidity and water holding capacity, it preserves food in a stable, secure state. By lowering product weight, it minimizes the expenses associated with raw material processing, packaging, and shipping. One of the primary challenges associated with the drying process of fresh foods and agricultural goods is the need to reduce the moisture content to a certain low level, while simultaneously preserving their qualitative characteristics such as color, texture, chemical composition, and shrinkage [117]. According to Da Silva et al., the utilization of drying as a preservation technique is imperative due to the impracticality of refrigeration in prolonging the shelf life of perishable fruits such as dragon fruit

[121]. Phenolic compounds in dragon fruit were thermally destroyed by the prolonged drying time due to their sensitivity to heat [122]. The polyphenols' oxidative destruction was aided by the extended hot air exposure drying, which led to a reduction in the quality of the dragon fruit's TPC. Hot air drying of plant material may result in quality degradation due to colour reactivity and active component breakdown [123-124]. This could be attributed to pigment breakdown during the drying process and browning reactions, which resulted in colour changes [125]. The fluidized bed dryer (FBD) and heat pump drier, has been utilized to replace the traditional hot air dryers for the drying of dragon fruit.

Wiset et al. contrasted the sun drying method with heat pump drying (45˚C) and FBD (110˚C) for the antioxidant activity and bioactive compounds of dragon fruit peel. The drying techniques have altered the red colour of the peel, which is caused by the pigment betalain. The peel has a brown colour after being sun-dried. In comparison to sun drying, heat pump and fluidized bed drying greatly increased the antioxidant activity and betalain content of dried peel [126]. Purees of white- and red-fleshed dragon fruit (Hylocereus spp.), and the effects of heat processing on their physicochemical, color, antioxidative, and rheological properties, were demonstrated by Liaotrakoon et al. Antioxidant activity was evaluated using the TPC test, the DPPH assay, and the FRAP assay. Isothermally heating the purees of dragon fruit to 50, 60, 70, 80, and 90 °C for 60 minutes was used for the analysis. The unheated red dragon fruit exhibits approximately twice the quantity of total phenolic compounds and antioxidative properties, as measured by FRAP and DPPH assays, compared to the unheated white dragon fruit. The color of purees is contingent upon the temperature and duration of heating. The white dragon fruit and red dragon fruit exhibited a considerable change in color, becoming browner and more prominent, when subjected to prolonged heating at elevated temperatures. It may be inferred that subjecting a substance to temperatures over 80 °C results in more noticeable alterations in color compared to heating within the lower temperature range. The findings of this study indicate that there is a notable increase in antioxidant activity as a result of prolonged heating at higher temperatures. This observation is of particular importance [114].

3.4. Impact of storage, packaging and transportation on antioxidant activity

The food and pharmaceutical industries have widely recognized benefits from using dragon fruit. Due to the presence of betacyanin in the fruit, dragon fruit is frequently utilized as a natural colorant for a range of purposes. Dragon fruit is frequently employed in the commercial production of dragon juices [127], jelly [128], yoghurt [129] and jam [130]. Due to their high moisture content and the fact that after being harvested, these items continue to undergo metabolic activity, they require careful packaging and storage to prevent rapid deterioration. Consistent changes in the physical and chemical characteristics are evident as the fruit ripens. Furthermore, the removal of fruit from cold storage gives rise to physiological concerns, which manifest as translucency and browning of the outer flesh, darkening of the scales, softening, shrivelling, and a deterioration in flavor [131]. Chilling injury (CI) is a physiological condition that can adversely affect dragon fruit when it is subjected to prolonged storage at suboptimal temperatures. As a result, the recommended temperature for the storage of dragon fruit is 5°C, and it is advised not to deviate from this range in order to prevent cold injury or accelerated fruit deterioration.

The nutritional value of the fruit also influences how well it is perceived by consumers, in addition to its exterior look and attractive appearance. The bioactive components of the fruit have undergone noticeable alterations, which also have an impact on the fruit's art of beauty and nutritive qualities. Even though there may be benefits, there are two important issues that must be resolved: the fruit's short shelf life and the limited bioavailability of betanin [132-133]. Each food item has a unique shelf life due to the many processes it underwent during development. A food product's shelf life forecast must be done in order to ascertain its expiration date. The shelf lives of dragon fruit at 10°C and 5°C with 90% relative humidity are just 14 and 17 days, respectively [134]. The shelf life of dragon fruit is constrained by several factors, such as elevated respiration rates, loss of weight, and an expedited ripening process leading to fruit shrinkage beyond the eighth day post-harvest[135]. High temperatures, which cause rapid ripening and early loss of fruit quality in tropical climates, are the principal factor that shortens the shelf life of fruit. To preserve the necessary active components and stability of dragon fruit, effective storage and extra processing might be very helpful.

Lipid peroxidation process is one of the main causes of degradation of food and pharmaceutical items during processing and storage and antioxidants inhibits this process by scavenging free radicals and prolong the shelf lives [136]. Furthermore, the antioxidant activity of phenolic acids will vary at different temperatures based on the content of the phenolic acid itself [137]. To retain fruit quality and improve its shelf life, physiological activities must be slowed down. The dragon fruit has undergone a variety of physical and chemical preservation techniques, including edible coating, thermal treatment, chemical treatment, and packaging. Dragon fruit has been subjected to fermentation technology in an effort to increase its antioxidant activity, shelf life, flavor, and marketability [138].

The commercially produced fermented red dragon fruit beverage includes more antioxidants [107] ,compared with the fruit pulps of red dragon fruit [139] and [140]. Ali et al. studied the antioxidant activity of dragon fruit using the FRAP assay and developed a double layer coating of 600 nm droplet size+1.0% submicron chitosan dispersions and conventional chitosan. The purpose of this coating was to enhance the barrier property of the coating material, thereby preserving the quality of dragon fruit during storage at a temperature of 102 °C and a relative humidity of 805% for duration of 28 days. According to Ali et al., the utilization of a biodegradable and cost-effective double layer coating has the potential to effectively preserve the quality of dragon fruit for a period of 28 days, without causing any undesirable flavors. This coating can serve as a viable substitute for synthetic packaging materials and fungicides, thereby enhancing the shelf life of dragon fruit [141]. The shelf life of red dragon fruit jam was calculated by Anwar et al. using the Accelerated Shelf Life Test (ASLT). The bottle-stored dragon fruit jam was kept at 30, 40, 50, and 60°C and every seven days (day 0, 7, 14, 21, and 28), observations was made. It has been tested using the DPPH and TPC tests. The TPC findings were maximum when stored at 30°C, whereas results were relatively lower when stored at higher temperatures (40, 50, and 60°C). As a result of the storage for 28 days at 30, 40, 50, and 60°C, the antioxidant activity continuously declined. Compared to samples that were stored at 30, 40, or 50°C, the declines were more pronounced in samples that were stored at 60 °C. The temperature and duration of storage have a significant impact on the antioxidant activity. Red dragon fruit jam has a predicted 99-day shelf life when kept at 28°C. Furthermore, the results of the study provided evidence that the antioxidant activity exhibited variable levels and was prone to breakdown under elevated temperatures in the jam [142]. Six distinct types of dragon fruit were stored at 5°C and 10°C, and Obenland et al.[143]noted that this resulted in a little darkening of the interior pulp colour. While fruit was being stored at 5°C, the antioxidant activity declined; however, at 10°C, it remained unchanged, and the concentration of betacyanin was exactly as expected upon harvest. Using four distinct salicylic acid (SA) concentrations (0.1, 1, 2, and 5 mM) and methyl jasmonate (MJ) concentrations (0.01, 0.1, 0.2, and 0.5 mM), Mustafa et al.[144] pretreated the dragon fruit for 21 days at a cold storage temperature (6°C). During the experiment, it was shown that MJ boosted betacyanins as well as antioxidant activity and had no significant influence on ripening, whereas modest doses of SA delayed the process of ripening.

The majority of the fruit in the Indian market still originates from export, despite the good development in production figures, thus it is important to uphold quality standards across the marketing channel. Maintaining the ideal RH (90%) and temperature (5°C and 10°C) throughout the shipping of dragon fruit, however, is rather challenging. As a result, the losses that occur during the several stages of storage are significant, but they can be reduced with correct handling and packaging techniques and by making cold storage facilities more accessible to local producers, such as farmers. Before cultivars implement modern storage systems, there are a number of key aspects that must be taken into account. These include accessibility, storage capacity, sustainability, and cost. Fruits that have been harvested need to be handled with caution and put in protective containers in order to reduce skin abrasion and compression harm. Fruit weight decreased and unattractive shrivelling was caused by water loss. The most important variables that affect the type and severity of damage to dragon fruit are optimal maturity, the right time for harvesting, and adequate packaging. A promising strategy to lessen quick shrivelling and water loss during storage is to package fruit in a variety of packaging materials.

The influence of film wrapping on the extension of dragon fruit's shelf life has been demonstrated by Chandan. [145]. All of the fruit was wrapped in clear plastic (0.8 μ) and stored under three different conditions: high temperature (24°C), intermediate temperature (16°C), and low temperature (6°C). High temperature represents ambient storage, intermediate temperature represents controlled storage, and low temperature represents cold storage. After 15 days of storage, the fruits that were wrapped in film and kept at 6°C remained unaltered. Using modified atmosphere packaging (MAP) along with low-temperature storage, Castro et al. conducted research aimed at enhancing the storage capacity and prolonging the shelf life of dragon fruit. High-quality fruit of exceptional grade were harvested approximately 25 to 30 days following the flowering stage. These fruits were then carefully enclosed in polystyrene fruit cups and subsequently packaged in individual plastic bags made of non-perforated polyethylene (PE) and polypropylene (PP) materials, with a thickness of 50.8 m. Fruit that was MAP-stored at 5°C for up to 6 weeks didn't shrink, retaining its firmness and bracts' green colour. The overall phenolic content of all fruits declined over the course of the 6-week storage (5°C) and post-storage (20°C), but with the MAP packed fruit having a higher phenolic content than the control fruit, which is what allowed the antioxidant activity to be maintained [146].

The perishable nature of dragon fruit necessitates the implementation of additional measures to ensure its optimal cultivation, harvesting, handling, storage, processing, and transportation until it reaches the market for distribution. The establishment of an effective and dependable marketing route for the transportation of fruit to remote areas poses a considerable challenge, considering that a large proportion of fruit is primarily prepared for immediate consumption. To bolster the industry, it is imperative to intensify efforts in postharvest research and development programs. Dragon fruit has been utilized in the production of many commodities, such as juice, jam, jelly, powder, wine, and more, in order to confer economic worth.

According to Mohd, A. F [147], concentrated dragon fruit juice has a longer shelf life and requires less transportation than fresh juice. Due to its long shelf life, great economic worth, and simplicity of incorporation as a natural colorant in a variety of processed goods, dragon fruit powder is widely used. A commercial method called spray drying is used to extract powder from various fruit liquids while retaining the most nutrients and other active ingredients. When compared to raw fruits, the spray-dried powder has the advantages of being easily reconstitutable and transportable in ambient circumstances, which lowers the cost of transportation overall [148]. Red-fleshed dragon fruit (*Hylocereus polyrhizus*) juice's storage stability, betacyanin degradation kinetics, and sensory acceptability were all shown to be affected by juice concentration by Siow and Wong [127]. Juices can be effectively preserved using concentration because it lowers the moisture content to a point where the water activity is too low to allow degradation processes. Relative solids concentration should be raised often by this process. According to the study's findings, betacyanin was more stable in concentrate samples than it was in juice samples and was better retained when stored at 4°C as opposed to 25°C. Due to the smaller required storage volume, the concentrated product lowers transportation and storage expenses.

In order to prevent damage to the fruit during transportation, it is cleaned with normal water and dried naturally with a clean towel and then placed in a nylon bag. The fruit is then organized in a carton box with baffles. The appropriate size, quantity, and weight measurement is necessary. The most crucial phase is weighing, which necessitates precise weighing to protect the reputation of the consumer. The dragon fruit is then packed in a unique carton box designed for exporting produce. The product should be fastened after stacking so that it may be transported and stored while being kept chilled. Stacking should be done softly and without packing it too tightly. Following packaging, dragon fruit is placed in a cold storage facility where it is kept cold at a temperature between 2.2 and 4.4°C. The cold storage's process control and temperature control are handled entirely by an automated system [149].

4. Discussion

A substance that can prevent other molecules from oxidizing is an antioxidant. Antioxidants are any compounds that can prevent, postpone, or slow down the development of rancidity or other flavor deterioration in food as a result of oxidation. After this point, adding antioxidants usually has little influence on the development of rancidity. Dragon fruit hold attention from customers due to its exotic appearance, vivid red exterior, greenish scales, white or occasionally scarlet flesh, nutritional value, and antioxidant content [12, 33, 150-151]. The impact of antioxidant activity on the extraction process, heat drying, storage, packaging, and transportation has been summed up in this review.

As shown by previous research, phenolic acid (like gallic acid) and polyphenol (like flavonoids) have a significant relationship with antioxidant activity [152]. Gallic acid is frequently utilized as the reference standard chemical, and results are represented as gallic acid equivalents [36]. Due to their ease of use, speed, sensitivity, and reproducibility, the TPC test and DPPH assay have received the majority of attention from authors. There are numerous extraction methods that have been used, including maceration, MAE, UAE, and supercritical fluid extraction, which demonstrates that new extraction methods are superior to traditional methods in terms of preserving antioxidant activity [25]. The type of solvent used affects the antioxidant activity. The antioxidants have been extracted using a variety of solvents, including methanol, chloroform, ethanol, and water. According to a study by [36], peels contain higher antioxidant levels than foliage when extracted with chloroform, and when extracted with methanol, peels had lower antioxidant activity than foliage. Compared to chloroform extraction, methanol extraction yields a higher total phenolic content (TPC), according to this study. This ensures that both polar and non-polar chemicals can be extracted using methanol solvent, whereas only non-polar compounds can be extracted using chloroform solvent. In Red Dragon Fruit, Normala and Mardhiah [113] used ethanol, methanol, and water to demonstrate ant oxidative activity. Even while ethanol solvent extraction outperformed methanol and distilled water, all solvent extractions hold the potential to be a source of natural antioxidants. This study contrasts with the study conducted by Som et al. [36], possibly as a result of the different fruit sources and stages of maturation used in the experiment. Utilizing optimization strategies during extraction increased their effectiveness in maintaining antioxidant amount and quality while also enhancing the active constituent [104]. It is evident that the antioxidant activity of dragon fruit is influenced by both extraction time and temperature [110]. Commercial items that include more phenolic components, such as peel powder [23], fruit juice[104], and functional drinks [110], are also assessed for their antioxidant efficacy. The peels and fruit juices of dragon fruit have been used to extract pectin and betacynin, which have better antioxidant action. Various reported antioxidant activity of dragon fruits and its commercial products has been depicted in **Table 4**.To define the active component and determine the antioxidant activity, a number of hyphenated techniques including UPLC-QTOF-MS/MS, LC-MS, and ESR have been used [95, 103-104, 112]. Using an aqueous extract of *Hylocereus undatus*, Mahdi et al.[105] biosynthesized green AuNPs and tested their antioxidant activity. The results revealed that green AuNPs had greater antioxidant activity than the *Hylocereus undatus* fruit alone, indicating that the fruit is a good source of dietary antioxidants.

In order to boost the antioxidant activity of dragon fruit, novel drying processes such heat pump dryers and FBD have been developed. Thermal processing and drying time both have an impact on the antioxidant activity and bioactive compounds as well as the colour of the compound. When high temperatures are used to dry products, the rate of drying is often quick, but suitable drying processes should be used to preserve the fruit's colour and maximize antioxidant activity. The alteration in colour during drying can have an impact on the oxidation, enzymatic browning, non-enzymatic browning, and phenol polymerization processes as well as the degradation of pigment [153]. The traditional sun drying procedure required the longest drying time due to the low drying temperature needed to get the peel's high moisture content down to a safe level. The beneficial chemicals in the peels are oxidized by oxygen, which causes this. Oxidation is a problem that is also brought on by sunlight exposure. The employment of heat pumps in heat recovery enables the upgrading of heat from relatively low-temperature sources to higher temperatures as well as the recovery of latent heat from streams with high relative humidity. Although the initial cost of the heat pump drier was more than other systems, it proved more cost-effective than other systems despite producing dried agricultural products with better colour than those produced with traditional hot air dryers [154-156].The advantages of a fluidized bed drier include homogeneous product moisture content from complete grain and drying air mixing and rapid drying rates from a large product to drying air contact area. As can be observed, compared to the other procedures, sun drying produces the most colour change and has the least antioxidant activity.

Liaotrakoon et al.[114] have demonstrated the effect of thermal treatment on the antioxidant activity of puree from white and red dragon fruit. The ant oxidative qualities improved following thermal treatment. The observed outcome can be attributed to the liberation of certain antioxidant chemicals from the dragon fruit seeds within the puree as a consequence of heat processing. The use of heat during treatment has the potential to disrupt the cellular structure of seeds, leading to the release of antioxidant molecules. Alternatively, it is plausible that the occurrence of the Maillard reaction, as evidenced by the development of browning pigments, could generate antioxidant properties during the thermal treatment process. Researchers have used spray and freeze drying to protect the nutritious components of peel powder. When comparing the expenses associated with transportation, it is worth noting that the spray-dried powder offers certain benefits such as ease of reconstitution and suitability for shipping in various environmental conditions [148]. In a study conducted by Lee et al. [157], it was shown that the highest powder yield, approximately 60%, for spray-dried red and white pitaya fruit was achieved when the threshold inlet air temperatures were set at 120°C and 110°C, respectively. The antioxidant properties of the powder remained unchanged during storage and were not affected by a relative humidity of 33%. The retention of red color was shown to be superior in the spray drying method compared to drum drying when applied to the peel.

Numerous factors, including temperature and environment, have an impact on postharvest fruit quality. This is due to the fact that fresh fruit undergoes metabolic activity soon after being harvested as a result of endogenous activity, respiration, external influences, water loss, damage, and storage conditions [158]. For perishable goods like fresh fruit, packaging has been devised in an effort to preserve quality while extending shelf life. Modified atmosphere packaging (MAP) provides the capacity to alter the oxygen content within the package by offering different degrees of gas exchange permeability. As a consequence, the respiration rate is modified, resulting in alterations to metabolic processes, microbial growth, and reduced enzymatic degradation. These modifications are implemented with the objective of enhancing the fruit's shelf life and preserving its antioxidant potential [159]. In order to generate a changed atmosphere surrounding the packaged fruit, MAP often uses polymeric sheets with various permeability for O_2, CO_2, other gases, and H_2O. MAP is a well-known method for increasing the marketability and storage life of fruits and vegetables. The maintenance of a high relative humidity, minimization of water loss, prevention of contamination during handling, and preservation of the postharvest fruit quality are all advantages of film packaging. Typically, colour is assessed since, along with texture, as it is one of the key characteristics that define the freshness and marketability appearance of the majority of fruit [160]. For commercial plastic packaging of food goods, polyethylene (PE) and polypropylene (PP) are frequently utilized.

In a study to increase the shelf life and antioxidant activity of dragon fruit, Chandran [145] demonstrated that fruits packed in film and kept at 6°C remained unchanged after 15 days of storage and that all fruits kept their peel colour for up to two weeks when kept at low temperatures because low permeability plastic film packaging prevents oxygen from penetrating the product [161]. The oxygen level in the sealed bag drops as the fruit undergoes respiration, while the carbon dioxide level rises. By doing this, it will be ensured that the fruit's respiration rate is slowed down and the consumption of respiration substrates is delayed. The quality of postharvest fruit can ultimately be preserved with easy modified environment storage. From the study by Castro et al.[146], it is clear that the effectiveness of MAP in conjunction with low temperature storage, the retention of phenolic content in packed fruit is more than the control during storage.

Table 4: Reported antioxidant activity of Dragon fruits and its commercial products

Dragon fruits and its commercial products	Reported antioxidant activity
Raw fruit peel (methanol extract)	97.42 ± 0.0061% [36]*
Raw fruit foliage (methanol extract)	88.81 ± 0.0012% [36]*
Peel powder	11.44 ± 0.98 mg GAE/100 mL [96] **
Peel section	81.91% [91]*
Fruit juice	73.38 ± 2.24 % [43]*
Polysaccharide from dragon fruit peel	70.17% (5 mg/mL) [102]*
Gold nanoparticle of dragon fruit extract	73.31 % (60µg\ml) [105]*
Rosella extract and dragon fruit extract functional drink	65.057 % [110]*
Puree	30.43±0.07b (µg GA/g)for White dragon fruit and 63.53±0.89 for red dragon fruit (µg GA/g) [114]***
Fermented dragon fruit juice	13.720 [94]#

represents IC50 value *represents % free radical scavenging activity **represents DPPH value in mg GAE/100 mL ***represents DPPH value in µg GA/g

GAE Gallic Acid Equivalent, GA Gallic Acid.

Note: All values represents here as per DPPH assay result.

The delayed metabolic processes are what are responsible for this. Higher respiration, which caused the destruction of several phenolic compounds, as well as senescence and the collapse of cell structure during storage, may have contributed to the control fruit's lower phenolic content [162]. Furthermore, it may be argued that the utilization of MAP in combination with a low temperature of 5°C offers the potential to increase the storage period of dragon fruit, hence extending its availability beyond the typical season in October. In the context of this combined therapeutic approach, it is feasible to ensure the local supply of dragon fruit until the month of December, at which point its price experiences a surge as a result of the market's increased reliance on imported types.

Moreover, the implementation of this storage mechanism enables the potential expansion of markets to other regions requiring a 30-day shipping delay, similar to the export market from Vietnam to Europe. The utilization of polystyrene fruit containers in all treatments, including the control group, resulted in improved fruit quality by effectively preventing the bracts from breaking throughout handling, shipping, and storage processes. The levels of antioxidants in fruit are subject to variation based on factors such as growth methods, maturation stage, and cultivation conditions; the amount of vitamins and minerals is impacted by the transportation and storage of the fruits.

The utilization of suitable packing materials, in combination with effective decay mitigation measures, is crucial for minimizing weight loss and prolonging the shelf life of products during storage. In addition to being cost-effective and readily available, it is imperative for the packaging material to possess environmentally sustainable attributes. The best suited condition that enhances the antioxidant activity of dragon fruit are depicted in **Fig. 4.**

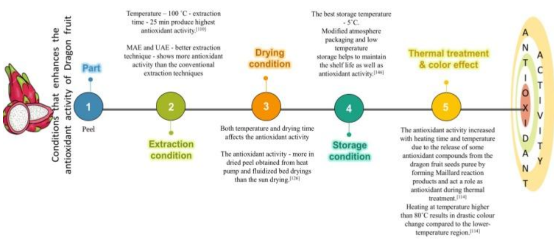

Fig. 4. Best suited conditions that enchances the antioxidant avtivity of Dragon fruit

Here are a few different instances of maintaining antioxidant activity. According to reports, pitaya peels contain a variety of bioactive, phenolic chemicals and can be used as an ingredient in food additives for the manufacture of bakery goods. Cookies or biscuits make up a large portion of the many baked products sold in the markets. Ho and Abdul Latif [163] attempted to add DPP, a substance with excellent antioxidant effects, to improve the food's nutritional value. The impact of various cutting techniques on the quality and antioxidant activity of pitaya fruit during 4 days of storage at 15°C was examined. Pitaya fruit was cut into slices, halves, and quarters, all of which were 1 cm thick and had varying degrees of injury. The findings revealed that fruit quality indicators such vitamin C, soluble solids, titratable acidity, and flesh colour were not significantly impacted by cutting methods. During the initial storage period, fresh-cut processing increased the activity of antioxidant enzymes such catalase, superoxide dismutase, and glutathione reductase and encouraged the production of reactive oxygen species (ROS). These findings showed that cutting methods didn't significantly affect the organoleptic quality of fresh-cut pitaya fruit, but they did considerably increase the biosynthesis of phenolics and elevate its antioxidant potential. Thus, it is conceivable to give consumers with freshly cut pitaya fruit rich in phenolic antioxidants in regular diets by simply adjusting cutting styles and raising wounding intensity [164]. Statistical representation of methods reported on the antioxidant activity of dragon fruit from 2009 to 2022 has been depicted in **Fig. 5.**

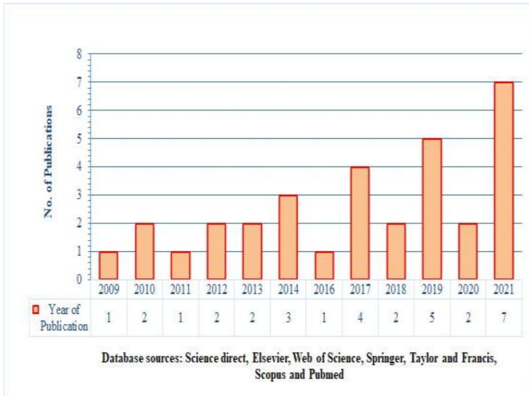

Figure 5. Statistical representation of methods reported on the antioxidant acitivity of Dragon fruit from 2009 to 2022

5. Conclusion

Due to the rising demand for fresh dragon fruit, the worldwide dragon fruit market, is expanding quickly. The cultivation of dragon fruits is aided by exceptional weather and high production capacity.

Although it has a delicate flavor and offers tremendous antioxidant benefits, consumers frequently complain that the food occasionally lacks sweetness and has a bland flavor [165]. This has caused the sweeter yellow dragon fruit to be imported into North America and Europe from Colombia and Ecuador. The quantity of phenolic hydroxyl groups had a significant impact on the antioxidant and radical-scavenging abilities of the antioxidants. Recent decades have seen a rise in research into the antioxidant activity of foods and diets due to the growing body of evidence linking oxygen free radicals to the onset and progression of cardiovascular and neurological illness, senescence, and cancer [166]. Additionally, the polyphenol betacynine found in dragon fruit is mostly accountable for the fruit's antioxidant properties.

Although there have been numerous studies on the antioxidant properties of white and red dragon fruit, there is still a dearth of information on other dragon fruit species, particularly yellow dragon fruit. On the antioxidant properties of yellow dragon fruit, further research needs to be done. The susceptibility of the southwestern region to the impacts of climate change necessitates a focus on the dragon fruit as a means to promote the sustainable utilization of ecosystems and biodiversity in that area. The efficacy of the experimental planting paradigm for the climbing cactus in mangrove regions can be ascribed to the pitaya's robust adaptability and resilience in the face of diverse and challenging environmental conditions, particularly those characterized by elevated saline levels. More research is still required to fully comprehend the adaptation mechanisms driving the dragon fruit's salinity tolerance and to choose genotypes that can thrive in the increasingly extreme conditions brought on by climate change [167]. More research should be done to determine the dragon fruit's optimal growing conditions and climatic conditions for maximal antioxidant activity.

In future, more in-depth research will be needed to improve the antioxidant activity by optimizing production conditions and usage in practical goods (like food or pharmaceuticals) with established technical or clinical efficacies. Dragon fruit's bioactivities have been shown in several *in vitro* studies, although details on the antioxidants bioaccessibility or bioavailability are still lacking. In the future, authors ought to focus more on in vivo tests of antioxidant activity and develop their clinical evidence. More research is needed in order to increase the trading potential for pitaya-derived processed products, which are currently scarce on the market. Although dragon fruit has been used to make a variety of products with additional value, there is a needless marketing gap for the goods on the international market. To make the most use of dragon fruit, it is important to raise awareness of the potential antioxidant advantages of the products that have been valorized [30]. In order to examine its limitless application by the food, pharmaceutical, and cosmetic industries, more research is necessary until accurate and consistent data are available.

Despite its potential for financial gain, the dragon fruit sector faces considerable challenges due to its seasonality (from July to October) and the fruit's short shelf life even at low temperatures. Environmental dangers, biological stress, and national government laws are just a few of the many variables that have a significant impact on the development of dragon fruits [168]. Unfortunately, there are difficulties in growing dragon fruit that reduce its potential for optimal output. As a result, it's important to recognize the diseases that affect dragon fruit in order to keep track of their rising prevalence.

Monitoring for diseases would be essential to maintain plant biosecurity because fruits are exported and imported. In order to ensure plant biosecurity, disease surveillance is essential because fruits are exported and imported [169]. To prevent mechanical damage that tears the cuticle and produces more water loss and the possibility of disease development, postharvest handling should be enhanced. It is anticipated that these modifications will raise consumer appeal, grow demand, and retain the antioxidant activity. In this way, a new era of dragon fruit research will emerge, allowing people to accept dragon fruit as a powerful antioxidant whether it is consumed in its raw form or as a processed form.

6. Conflicts of interest

No potential conflict of interest was reported by the authors.

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