Exploring *Hylocereus spp* and Its Potential Applications: A Review

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This review plans to provide an overview of the *Hylocereus spp* as a whole, focusing on their morphology, how they are propagated and cultivated, what are the optimum conditions for them to be propagated and cultivated in, their nutritional and medicinal benefits, and the application of these plants in different industries such as cosmeceuticals, food and beverage, wastewater treatment, and its potential uses in oil and gas industry. Pitaya is becoming increasingly popular as a staple crop in different countries across various regions from Central America to Asia due to its rich nutritional make-up making it an excellent source of dietary fibre, vitamins, fructose, and minerals. Moreover, cultivators are attracted to this plant species due to their relatively high yield and the crop's longevity, with one plant lasting up to 25-30 years. At the moment, there is very little information on maximising the full potential of this plant's uses and benefits to consumers and industries across the world. Hence, this review may provide a guideline and detailed background to develop a better understanding of the pitaya plant including the fruits as well as the by-products, and expand the market and its applications in different industries.

Keywords: *Hylocereus spp*; bacterial application; cosmeceuticals

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Pitaya or more commonly known as dragon fruit is the fruit of a *Hylocereus spp.* which falls under the cactus family Cactaceae [1]. There are various unique names given to this beautiful vine cacti species across the multiple geographical regions where it is found. The plant itself is often referred to as the "Noble Woman" or "Queen of the Night" due to its flower blooming during the night. Meanwhile, its fruit has taken up other names some of which include night-blooming cereus, strawberry pear, Belle of the Night, Jesus in the Cradle, Conderella plant, päniniokapunahou or päpipi pua (in Hawaii) [2-3]. However, despite the many names given to this fruit, it is more commonly known as pitaya (scaly fruit) and dragon fruit due to the "dragon-like" scales or bracts on its skin [4].

The *Hylocereus spp.* has been found to be native to the tropical and sub-tropical regions of Southern Mexico and Central America along the Pacific side of Guatemala, Costa Rica, and El Salvador [3, 5-6]. Over the years, the fruit species has spread from its native origins across various regions including tropical and sub-tropical Americas, Asia, Australia, and the Middle East [7-8]. Moreover, this crop gained high popularity across Asia and South-East Asia due to its nutritional value, exotic features and colour [9-10]. Furthermore, dragon fruit has been well-cultivated across many countries because of its minimal water requirement and its ability to acclimatize to extreme high temperatures [11]; these countries consist of namely; Australia, Cambodia, China, Israel, Japan, Nicaragua, Peru, Philippines, Spain, Sri Lanka, Taiwan, Thailand, South-Western USA and Vietnam, Ecuador, Thailand, Indonesia, and Malaysia [7-8, 12]. In Malaysia, dragon fruit was first introduced and cultivated in two states namely Setiawan, Perak and Kuala Pilah, Negeri Sembilan in 1999 [4].

Furthermore, pitaya is expected to be one of the most economically vital fruit species to be cultivated across the world due to its well-known medicinal and nutritional properties [13-14]. In addition, this fruit's ornamental value has made it a popular choice of crop for growers across the globe [15]. However, despite its gaining popularity and rising demand, its export is hindered due to its very limited and short-shelf life of only few days at room temperature [16]. Therefore, despite being one of the largest exporters of dragon fruit, Vietnam focuses a large portion of its export to neighbouring Asian countries [17].

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(a) (b)

Figure 1. (a) *Hylocereus spp* estate in Sepang, Selangor (b) *Hylocereus spp* plant exterior morphology.

As of now, there are limited studies focusing on *Hylocereus spp.* as a whole from various aspects. Hence, this review paper intends to provide an overview of dragon fruit in terms of its morphology, propagation, cultivation, nutritional benefits, and its application in industry according to the recent papers and research findings.

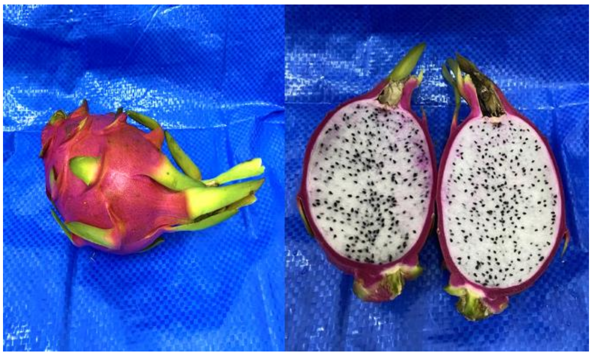
Morphology and Types of *Hylocereus spp*

Hylocereus spp. are a family of evergreen epiphytic cacti which are long-lasting and can grow up to 5ft to 8ft high with leafless, triangular, and fleshy joint stems [3, 18]. The tree's stems can branch out into few segments with each segment having the ability to grow up to 20ft long. Moreover, the segments have three wavy wings and often seen with one to three spines, or other times spineless [3, 19]. The roots of these plants are not the typical roots, as they are aerial roots found growing from under the stems from which not only it provides support for the plants to grow on walls, rocks, or other trees, but also it is the main absorber of water of these plant species [3]. Figure 1 shows the mature crop of *Hylocereus* plant.

As the name "Queen of the Night" suggests, the flowers of these plant species are nocturnal bloomers. It is an edible, fragrant, and showy flower which is often 1 foot long and 9 inches wide, giving it a bell shape [3, 20]. The dragon fruit flowers are typically white in colour [12], while the stamens and lobed stigmas are cream in colour [20]. The stem margin

Figure 2. Blooming fruit of the *Hylocereus spp* plant growing from a budding on the cacti leaves.

(a)



(b)

(c)

Figure 3. (a) *Hylocereus polyhizus* fruit – rounded fruit with short red peel and red pulp embedded with black seeds (b) *Hylocereus Undatus* fruit – oval shaped fruit with red and green peel and white pulp (c) *Hylocereus megalanthus* fruit – oval-shaped dragon fruit with a bright yellowish-green peel and white pulp filled with black seeds.

usually has 3 to 5 spherical buttons which has the possibility to change into flower buds within a two weeks period. These buds are often light green and cylindrical which can grow up to 11 inches within 16-17 days [20]. Figure 2 shows the mature flower buds of the pitaya plant.

Pitaya fruit can come in one of these two colours – bright red skin or yellow skin with green scales [1]. The pulp of the fruit also varies in colour depending on the species; the flesh could either be red, reddish-purple, or white [2, 20]. The flesh itself is entrenched with countless tiny black seeds [1, 20].

Amongst the species of pitaya that are cultivated there are a number of different varieties which are distinguished by the colour of the peel and pulp [10, 21-22]. There are two commonly cultivated dragon fruit varieties based on the colour of the fruit's pulp – white (*Hylocereus undatus*), red (*Hylocereus costaricensis* and *Hylocereus polyrhizus*); moreover, there is yet another type of dragon fruit which is rather different from the other species due to its unique yellow peel colour and white pulp – *Hylocereus megalanthus* [23-24]. The above-mentioned species are frequently cultivated in different countries. Thus, Figure 3 shows the three commonly types of dragon fruits that can be found in market.

Furthermore, there is yet another system for the botanical classification of the various *Hylocereus spp.* which was developed by Britton & Rose (1963) which provides a more precise classification of the species based on the following characteristics – size of the flower, shape of the fruit, size of the fruit scales, and the colour and texture of the pulp [25]. Britton & Rose (1963) identified five distinct *Hylocereus spp* as shown in Table 1 [2].

Propagation of *Hylocereus spp*

Pitaya can be propagated by either directly planting the seeds or planting the cuttings prepared from the plant stems. Once the seeds are planted, a seedling sprouts which will then take at least four to five years before it can yield flower and fruits. However, this waiting period can be cut short if propagation is done through planting of the stem cuttings which leads to flowers yielding in a period of only three years [26]. It has been shown that *H. undatus* and *H. costaricensis* can easily and naturally reproduce through stem cuttings [27].

Hence, stem cutting is a common propagation practice amongst cultivators. In order to improve the crop hardiness and resistance towards pest, cultivators must choose mature stems. Initially, either an entire stem segment or smaller portions of the stem (6-8 inches long) are prepared by cutting the stems at an angle which is known to lead to a more efficient rooting process. Once the cuttings are prepared, they cannot be planted directly; however, they are to be preserved in a cool and dry area for a period of 5 days to 1 week before they can be planted in either the field or a well-drained pot [3].

Table 1. Summary of classification of *Hylocereus spp* by Britton & Rose (1963).

Species Name	Flower Margin	Fruit Shape, Scale and Size	Pulp Colour and Texture
H. purpusii	Size: Large (25 cm) Margins: Outer perianth segments (more or less reddish), middle perianth segments (golden), inner perianth segments (white)	Shape: Scarlet and oblong Scale: Large Size: length: 10-15 cm, weight: 150-400 g	Colour: Red flesh with many small black seed Texture: Pleasant flesh and not very pronounced flavour
H. polyrhizus	Size: Long (25-30 cm) Margins: Outer perianth segments (reddish especially at tips), stigma lobes (yellowish and short)	Shape: Scarlet and oblong Scale: Various size Size: length: 10-12 cm weight: 130-350 g	Colour: Red flesh with many small black seed Texture: Pleasant flesh and good taste
H. costaricensis	Size: Long (25-30 cm) Margins: Outer perianth segments (reddish especially at tips), stigma lobes (yellowish and short)	Shape: Scarlet and ovoid Scale: Various size Size: length: 10-15 cm weight: 250-600 g	Colour: Red-purple flesh with many small black seed Texture: Pleasant flesh and good taste
H. undatus	Size: Long (29 cm) Margins: Outer perianth segments (green or yellow-green), inner perianth segments (white)	Shape: Rosy-red and oblong Scale: Large and long scales Size: length: 15-22 cm weight: 300-800 g	Colour: White flesh with many small black seed Texture: Pleasant flesh and good taste
H. trigonus	Size: Slender Margins: Spines (greenish to dark brown)	Shape: Ovoid and oblong Scale: almost smooth skin Size: length: 7-9 cm weight: 120-250 g	Colour: White flesh with many small black seed Texture: Pleasant flesh and not very pronounced flavour

However, if the cuttings are to be propagated in a field, certain parameters are to be matched. Firstly, the cuttings must be at least 50 to 70 cm long [28]; and most importantly they must have a sufficient and regular irrigation to maximise the chances of rooting. Under the mentioned conditions, approximately 90% of the cuttings should have rooting [29]. However, the time period for bearing varies from different regions depending on the regions' climatic conditions. For instance, in west Bengal, the pitaya stem cuttings take approximately 14 months to come to bearing [2].

Pitaya plant is a nocturnal bloomer; thus, it limits the natural cross-pollination from occurring. The flowers usually start their blooming around 6:40 – 7:00 p.m. and are completely open by 10:00 p.m. Typically a pitaya flower starts to wilt around 2 o'clock in the morning, which means that there is only a four-hour time window for pollination to occur. By dawn, the flowers are completely closed again. Moreover, the environmental conditions such as the temperature and the light intensity influence the opening of the pitaya flower [3]. The natural pollinating agents of pitaya are usually moths in the evening; however, to ensure a higher rate of successful pollination most cultivators carry out manual cross-pollination [30]. This process improves the fruit size and growth [3].

Upon pollination, it takes 28-30 days for the dragon fruit to grow and mature [31]; however, at this stage it is not ripened for harvest yet, the fruit needs a maximum of 50 days post-pollination to be fully ripe for harvest [32-33]. The physio-morphological characteristics of the dragon fruit are heavily influenced by the variety and flowering time in the pollination process [34].

Cultivation of *Hylocereus spp*

Dragon fruits are widely used as a commercial crop and they can be cultivated at a commercial level of between 1100 and 1350 plants per hectare. Each hectare of dragon fruit plantings can yield up to 20 to 30 tonnes of fruit for every harvesting cycle which is usually 5 to 6 harvests per year. However, it takes the plants up to five years to reach its maximum commercial production [20]. Despite its 5-year waiting period, it is an easy revenue generator due to its high and frequent yielding ability [35].

Just like any other commercial crop, in order to obtain and maintain the maximum yield of dragon fruit for every harvest, there are certain cultivation parameters which must be followed. To begin with, being an epiphytic plant, dragon fruit best grows in dry tropical and sub-tropical climates where there is sufficient sunshine and rainfall (600-1300 mm) and not too extreme temperatures (average temperature of 21-29 °C) [36]. If the plant is exposed to excessive levels of rainfall, it may cause the flowers to drop and the fruits to rot. Moreover, the moisture of the soil is very crucial to avoid the fruit from splitting; thus, water management and regular irrigation are amongst important factors to take into account during production [3]. These factors not only influence the growth of the pitaya plant but they also affect the flowering and setting of the dragon fruit itself [37-39].

One dragon fruit plant can continue to yield fruit for up-to 25-30 years provided that all the right conditions are met [40]. The fruit matures after 30 days post-pollination and can be harvested right away; however, to obtain a sweeter, more flavourful and bigger fruit it is recommended to postpone the harvest for an extra 20 days and only begin harvest on day 50. Despite the increase in sweetness, studies reported no significant change in the sugar content of the fruits harvested at 30 days and 50 days respectively. This study also found that the dragon fruits harvest at 50 days were 50% heavier than those picked at 30 days [41]. Once the fruit has reached its maturation stage, it is reflected in the colour of its peel which changes from green to red or rosy-pink or yellow in the case of *H. megalanthus* [1, 33]. Despite the fruits being bigger and sweeter if harvested later than 30 days, it is not recommended for every species of the pitaya plant. For instance, a study reported that *H. costaricensis* should be harvested right after 30 days to avoid the fruit splitting due to reaching its maximum peel pigmentation 4-5 days after reaching matured stage [42].

The harvesting of the pitaya fruit requires a special technique to prevent damage to the plant and the fruit itself. This involves the harvester to pick the fruit by rotating it clock-wise and twisting the fruit [42]. Dragon fruit is not a generally fragile fruit; however, there are certain precautions to be taken whilst handling and storage of the fruits post-harvest, especially with the *H. costaricensis* species due its fragile scales [2](Perween *et al.*, 2018). The fruits are to be stored in perforated bags in a dry and cool (4-5 °C) space to last for 25-30 days, although caution has to be taken in regards to the temperature as dragon fruit is prone to chilling damage. Despite being nonclimacteric, the fruit can only last less than 10 days if stored at room temperature [3].

Nutritional Values of *Hylocereus spp*

Dragon fruit has been recognised by the scientific community as a “superfood” due to its extremely high nutritional content [43]. Over the recent years, there have been a multitude of studies investigating the nutrient content of pitaya and majority of them have similar to almost same findings. These studies have found that dragon fruit is an excellent source of minerals such as potassium, phosphorus, sodium, magnesium, iron, and calcium [44-47]; at levels much higher than found in other fruits such as mangosteen, mango, and pineapple. It is also a good source of the dietary fibre, natural glucose and fructose as well [26]. Various studies have repeatedly found the pulp of dragon fruit to contain astoundingly high levels of the vitamins ranging from Vitamins B1, B2, and B3 and as well as Vitamin C [16, 48]. To provide a clearer image of the content found in this fruit, it has been found that 100 g of fresh pitaya pulp contains 6.3-8.8 mg calcium, 0.50-0.61 mg iron, 8-9 mg Vitamin C, and 30.2-36.1 mg of phosphorus [49].

Plants have a significantly high level of phenolic compounds and pitaya is no exception. The major phenolic groups found in the peels and pulps of dragon fruit have generally been recognized as flavonoids [50]. Moreover, recent studies investigating both red and white dragon fruits reported that there was a total of sixteen phenolic acids present in the fruits including eight benzoic acid derivatives, seven cinnamic acid derivatives, and ellagic acid, a dilactone of hexahydroxydiphenic acid with four hydroxyl groups [43]. Despite the high content of phenolic acids found in the pulp and peel, the seeds embedded within the pulp contain 50% essential fatty acids, namely linoleic acid and linolenic acid [14].

Pitaya is a low-calorie fruit yet abundant with protein content. Studies have reportedly found that the total protein content in red to white dragon fruit ranged from 0.887% to 1.11%. As for dietary fibre, the amount ranged from 0.806% (red) to 1.14% (white). The total reducing sugar content of the red and white dragon fruits varied from 5.13 to 7.06 g and 3.39 to 4.98 g, respectively, and the available carbohydrate content ranged from 5.42 to 7.32 g [43].

In addition to its rich nutritional value which consumers have started to notice, another factor which makes this fruit stand out from other types of fruit is its ability to tolerate draught and dry environments which makes it beneficial to those countries experiencing frequent draughts which typically causes crops to spoil [51-52].

Benefits of *Hylocereus spp*

Fruits are all beneficial to health, some more than others due to their varying mineral and nutrient content. Pitaya has been recognized as an excellent fruit to be included in one's diet. To begin with, pitaya has one of the lowest sugar and calorie content compared to other fruits which are regularly consumed. Therefore, it is believed to be an excellent fruit for weight loss. A recent study reported that white dragon fruit juice reduces the negative effects of a high-fat diet on insulin resistance, hepatic steatosis, and adipose hypertrophy in mice, but has little impact on body weight gain [53].

As discussed earlier, dragon fruit pulp and its seeds are rich with essential fatty acids namely linoleic acid and linolenic acid [14]. Ingestion of the essential fatty acids leads to a better-balanced ratio of LDL:HDL cholesterol which in turn results in reduced risk of developing hyper-cholesterol, improves brain function, reduced levels of triglycerides, and lower levels of LDL cholesterol [54-55].

Moreover, the fruit is rich with fibre, vitamins and various minerals which have been linked to reducing the risk of developing certain diseases such as bowel movement disorder, scurvy, anaemia, asthma, kidney disease, and bone weakness, provided that the fruit is consumed on a regular and sufficient basis [52, 55].

One of the most important health benefits of consuming pitaya fruit is its antioxidative and anti-microbial properties. Dragon fruit contains remarkably high levels of phenolic compounds namely flavonoids which has been identified as a secondary metabolite; due to its bioactivity it has displayed antimicrobial, antimutagenic, antioxidative, and anti-inflammatory activity when consumed [125]. In addition to the phenols, the peel and pulp extracts of dragon fruit reportedly have phytochemical compounds which are natural antioxidants [18]. Therefore, it can be safely assumed that consuming pitaya fruit as a regular dietary supplement is beneficial in the long term in terms of reducing the risk of developing various diseases such as cancer.

Besides being beneficial to the human health, the nutritional composition of dragon fruit has made it grab the attention of industrial researchers. For instance, the peel of the fruit contains pectin which can be extracted to be used as natural food thickener in low viscous food and beverages [56]. Moreover, another study found that the red flesh of pitaya fruit is rich in betalains which can be used as a natural and organic food colourant [2].

Application of *Hylocereus spp*

Alcohol Industry

The fermented dragon fruit drink is one of the newer brands on the market in recent years. Red dragon fruit is everywhere in the market and is very popular due to its richness in nutrients and source of antioxidants. However, fresh dragon fruit can only be kept for a maximum of 14 days at 10 °C and 5 days at room temperature [57]. As a result, it's preferable to make fresh fruit into fermented liquid dragon fruit to reduce waste and boost earning potential [58]. This was acknowledged by [59] in which they reported that since dragon fruit is perishable, fermenting it into alcoholic drinks or wine may be a cost-effective way to preserve it after harvesting. Thus, different brands of fermented dragon fruit drinks have been added to the local market in recent years namely; Pitacacti Delight, Forliko, Klau, and Sunberry [57].

Studies have found that coloured fruit wines are becoming increasingly popular due to the strong antioxidant activity provided by naturally occurring pigments [60]. As such, it is believed that drinking these fermented dragon fruit drinks improves overall body functions [61]. There have been studies investigating these findings regarding fermented dragon fruit drinks and it has been reported that the pigments in coloured fruit wines may have anti-cancer, anti-aging, anti-neurological disorders, anti-inflammatory, anti-diabetic, and anti-bacterial properties [60]. Additionally, fruit wine's exotic and well-balanced sweet, salty, and alcoholic flavours also help to suppress one's appetite. Alcohol, total carbohydrate content, titratable acidity and volatile acidity, and betacyanin content are all important measures of the finished dragon fruit wine's efficiency [62].

The pectic compounds are found in abundance in the peel and pulp of dragon fruits (38–47 percent dry weight) [63]. The addition of pectolytic enzymes to fruit wine produces significant changes in the chemical composition of the juice, which can influence the flavour, colour, and antioxidant ability of the wine flavour [64-66]. Up to the present time, there have been several publications on the fermentation of red dragon fruit into alcoholic beverages or the treatment of red dragon fruit with pectinase enzymes [67]. For instance, there has been studies surrounding the role of the *Saccharomyces cerevisiae* enzyme in the fermentation of dragon fruit wine, significantly in relation to fermentation rate and sugar conversion rate, and it is reported to be exceptionally well-suited and can thus be considered a yeast strain for wine fermentation [68]. In addition, the wine produced after fermentation contained 11.2 percent vol (v/v) alcohol, which met the criteria for low-alcohol health wine

Wine is considered a high-value brand that can be made from dragon fruits, in addition to the existing dragon fruit products. Thus, the use of dragon fruit in fruit wines has the potential to stimulate local wine production while also reducing alcoholic beverage imports [60].

Table 2. Extraction yields (%) of dry peels for *Hylocereus polyrhizus*.

	Ammonium Oxalate/Oxalic Acid 0.25%	0.03M HCl	Deionised Water
Yield of pectin, %	20.14+0.43a	14.96+0.36b	15.37+0.44b
Moisture, %	11.19+0.25a	11.13+0.7a	11.33+0.69a
Ash content, %	6.88+0.42b	11.95+1.55a	11.55+0.13a

Food Industry

The existence of phenolic groups that donate electrons or conjugate with metal ions also known as phenolic compounds, are a major category of phytochemical secondary metabolites with significant antioxidant properties [69]. Phenolic compounds found in fruits and plants can be categorized into four groups according to the number of carbon molecules and the complexity of the composition which are namely; flavonoids, phenolic acids, stilbenes, and lignans [70]. Along with their complex molecular structures, each phenolic group has its own set of characteristics [71].

The white (*Hylocereus undatus*) and the red (*Hylocereus polyrhizus*) pitaya are two of the most common varieties found to be high in phenolic compounds [69]. Thus, for the past years, the peel of the dragon fruit has been identified as a raw material for pectin extraction [72-74]. Pectin is used as a thickener, emulsifier, gelling agent, stabiliser, and fat substitute in the food industry [75]. Additionally, jams, soft drinks, fish and meat products, fruit juice, desserts, and dairy products all of which use pectin as a thickening, gelling, and emulsifying agent [76]. Pectin is the methylated ester of polygalacturonic acid that contains 1,4-linked α-D- galacturonic acid residues and is commonly found in higher plants' cell walls and middle lamellae [77]. The ability of these biopolymers to gel in aqueous solutions is an essential functional property and these applications specifically account for a large portion of pectin intake around the world [78].

As a result, the dragon fruit peels become an efficient and appealing source for pectin extraction. Many major pectin manufacturers use citrus peel or apple pomace as raw materials, all of which are by-products of juice (or cider) production. On a dry matter level, apple pomace contains from 10 to 15% pectin, while citrus peel contains from 20 to 30% [79]. The extraction method has been found to greatly influence the pectin yield of the harvest dragon fruit from 15% to 20.1% of the dry weight of the peel as summarised in Table 2 [75].

These findings have been further supported and clarified that the pectin yields from dragon fruit peels (17%) are comparable to apple pomace and marginally peels have more pectin than other food industries by-products like cocoa husks [80], peach pomace [81], and sunflower head residues [82].

Food colouring is used as a food additive solely to make the food looks more appealing in order to obtain a better selling price. Because of its pulp colour and antioxidant effects, red dragon fruit has a red peel and red pulp that can be used to make natural colour additives for nutritious food [69]. People across the world have traditionally used natural food colouring derived from nature [83]. Turmeric, saffron, assorted flower petals, paprika, and beet extracts, for example, are used as yellow, red, and other colours in a variety of foods to boost health potency. Scientists are becoming more concerned with the use of synthetic food colouring as more consumers are using it [84] but, in recent years, consumers' preferences have shifted towards natural food additives [83]. Unfortunately, synthetic food additives, on the other hand, are more readily available in the market when buyers have no other options.

Therefore, there have been studies attempting to introduce dragon fruit colouring powder (DFCP) which is a raw food dye made from dragon fruit albedo [83]. It is supposed to be extremely safe and appealing, especially to consumers. Natural food colourants are not only good for the human body, but also towards humanity and the environment. Since it is derived from the fruit's only disposable component (peel), DFCP is presumed to be cost-effective. In order to avoid waste, companies that produce dragon fruit products are highly suggested to broaden their production lines to include new products made from fruit peels. Flavonols, flavanones, and hydroxycinnamic acid derivatives are the most common phenolic compounds found in *Hylocereus spp* [50]. Betalains were formerly thought to be flavonoids, but research suggests that they contain nitrogen and do not change colour reversibly in the same manner that anthocyanins do with pH. Furthermore, the key ingredient (95%) of the red pigments in the extract is betacyanin [83] and the peel of the dragon fruit contains betacyanin, which can be used to make cosmetics and wellness items as well [85].

Dietetic fibres are made up of polysaccharides, oligosaccharides, and lignin, and their physicochemical properties determine their beneficial functions [86].

swelling capacities, viscosity, and texture enhancement, they have potential applications as fat substitutes in foods [87-89]. Dragon fruit peels are by-products of pulp production that are usually thrown out, but they are abundant in polyphenols, vitamins, and dietary fibres [90-91]. Thus, the peels may be used as fat substitutes, enhancing the nutritional value and functional properties of food [86]. Since pitaya peel powder contains a high number of dietary fibres, it is referred to as dietary fibre powder. When used as an ingredient in ice cream, pitaya peel flour can affect many product characteristics which include physico-chemical characteristics, colour, viscosity, and taste, as well as increase the ice cream's antioxidant capacity. It must be recognized that replacing fat-rich ingredients with pitaya fibre resulted in a substantial 73.5% reduction in lipid content. However, when the same process was done in lemon ice cream using orange fibre as source of fat, there was only a 51% reduction in lipid content [88]. In addition, the rheological, physical, and sensory properties of ice creams with 75% lipid content replacement by gum combinations were tested, and the findings showed that the ingredients were successful as fat replacers/stabilizers for low-fat ice creams [92].

Since the red pitaya peel flour has sufficient technical and physicochemical properties, as well as being an outstanding source of dietetic fibres and minerals, it illustrates that this fruit's by-product may be an excellent food component, enhancing the nutritious value of goods and reducing the likelihood of various chronic diseases.

Cosmetic Industry

As known as commercially cultivated fruits among the agricultures, dragon fruit crop has an extensive amount of waste products namely the peels and the seeds [93]; the approximate range of pitaya by-products is between 30% to 45% [94]. For instance, the waste products of *H. polyrhizus* is comprised of 22-44% peels and 2-4% seeds [63]. Hence, this shows that majority of the waste is coming from the peels of the fruits rather than the seeds or other parts of the crop [91]. The discarded dragon fruit peels contain significant levels of antioxidants, vitamins, soluble and insoluble fibre, pectin, and betacyanin pigments which are actually useful [93]. Similar to the decomposition of other bio-wastes, the decay process of pitaya wastes leads to production of toxic green-house gases and unpleasant odour [95-96]. Hence, rather than disposing the by-products of pitaya, numerous studies suggested to find alternative purposes such as development of natural cosmetics.

Despite the use of pitaya peels in various other industries such as agriculture and food, the peels have been proven to be useful in both medical and cosmetic fields due to their antioxidative ability, antiproliferative capacity [97] and moisturising function respectively [46]. It has been reported that the peels extract of dragon fruit contains between 92-93% of antioxidants [98]. Moreover, it has been shown that the peel extract has a more effective antioxidant activity compared to the pulp extract (Wu, *et al.*, 2006). Accordingly, 1 mg/mL of peel extract from red dragon fruit was able to reduce the reactive oxidative species (ROS) up to 83.48 ± 5.03%, whereas the same concentration of pulp extract from the exact same fruit was able to only inhibit 27.45 ± 1.02% of ROS [99]. Thus, this makes red dragon fruits peels waste a potential candidate to be used in making natural cosmetic products in order to treat premature ageing and eradicating acne resulting from excessive exposure to free radicals [98].

Due to the global warming issues happening around the world, there has been increased consumer demands on sunscreen products d for protection against UV radiation and development of skin cancer. There are 3 categories of solar UV radiation with different wavelengths namely; UVA (320–400 nm), UVB (290–320 nm), and UVC (200–290 nm). The penetration of UVA radiation into the skin can go as deep as 1mm into the dermis and epidermis layers, leading to the tanned effects (pigmentation of the skin) due to large amount of the emission of melanin pigment. However, the excessive exposure to this radiation can result in inhibition of immunological function, premature photo-ageing, and endothelial cell death, hence causing irreversible damage to the dermal blood vessels [100].

Despite the large volume of synthetic sunscreen products available in the market, the consumers are more prone to purchase the products which are plant-based due to its detrimental effects on human health including allergic and contact dermatitis, contact urticarial, photoallergic, and phototoxic reactions as well as solitary acute anaphylactic shock [101]. Other claims have also been made that pregnant women that apply the synthetic sunscreen product may result to delivering underweight babies [102]. In such cases, it helps to push the cosmetic industry to advance the formulation of the sun block with the active ingredients derived from plants. Hence, a study has been made on the skin of pitaya fruits, specifically *H. polyrhizus* species on its ability of antioxidant and photoprotection on skin. Thus, the peels of *H. polyrhizus* has been found to be extremely capable to serve as natural active ingredients in the lucrative cosmetic industry, replacing chemical sunblock agents. As the findings show the extraction peels of *H. polyrhizus* exhibited vastly higher absorption spectra (3.1-3.6) at 290-320 nm, as well as an exemplary sun - protective factor (SPF) value of 35.02 ± 0.39 at 1.00 mg/mL; the peel extraction also had wide ranging UVA and UVB shielding qualities. The use of *H. polyrhizus* peels extract would undoubtedly reduce the threat of numerous skin issues that might be triggered by the synthetic active components in marketable cosmetic goods to a far higher level. Likewise, residual volumes of these pitaya plants at the processing centre can be diminished significantly via enhanced postprocessing methods or in-plant reclamation and reuse of crop by-products [93].

Lips have historically been recognized as a critical component of total facial harmony and attractiveness, notably in females. As a result, the cosmetics industries formulate a product to boost the exquisiteness of the lips by its colours, texture and protection which is well known as lipstick. The consumers of this industry are primarily women; the market value of lipsticks and lip care products has progressively grown in order to fulfil their needs [103]. Although there are numerous shades of lipstick commercially available, it has increasingly become the focus of various health experts due to the safety concerns during prolonged exposure. Most of the lip care products that are currently found in market were reported by the consumers to often trigger reactions or discomfort like the lips become dried, cracked and wrinkly; this may occur due to the uses of chemical ingredients in the formulation of the lipstick. Coal tars are typically utilized as colourants to create the colour of lipstick, and it has been discovered to have detrimental effects on human health such as allergies, nausea, irritation, chapped lips, and may induce deadly carcinogenicity [104]. Hence, studies have been made to formulate the plant-based lip care products.

Recently, the awareness of using synthetic made beauty product has been increasing amongst the consumers. Thus, a study attempts to develop organic lipsticks featuring betalain pigments derived from *Hylocereus polyrhizus* [104]. When formulating lip-care products both organoleptic and medicinal properties of the formula ingredients are advised to be analysed and thoroughly tested to ensure the safety of the product. According to the results of the study done to develop organic based lipsticks using betalain pigments obtained from *H. polyrhizus*, the lipsticks displayed significantly stronger antimicrobial and antioxidative characteristics compared to the synthetic products, while maintaining the satisfactory organoleptic properties such as their spreading, hardness, shine and gloss. For instance, the data from the DPPH radical scavenging assay reported that the IC_{50} of the pitaya-based lipstick was 54.29 µg/mL in comparison to the 14.56 µg/mL IC_{50} of the control lipstick (formulated with ascorbic acid). Therefore, it can be observed from these findings that by adding in organic ingredients namely olive oil, dragon fruit, and vegetable fat; not only it aids medicinal properties to the lip-care products but also effectively replaces the synthetic ingredients such as lanolin and isopropyl myristate which cause dark pigmentation of the lips. Hence, such formulation addresses the health concerns faced by consumers of lip-care products and allows them to confidently purchase and use such products, making them an economical and effective cosmeceutical product [104].

Waste-Water Treatment

Water, air, and food are three of life's most valuable resources, but they have been taken for granted as the continuous technological growth has become the boundary of today's world [105]. Moreover, for the past few decades, one of the biggest global concerns of humanity has been accessed to clean drinking water [106]. As a result, proper water treatment and sanitation are needed to eliminate turbidity, impurities, and other pathogenic bacteria, which can be aided by the use of coagulants [105]. Coagulation and flocculation are common water treatment systems in developed countries, and alum is often used as a coagulant [106]. Moreover, it has been reported that coagulation-flocculation process is an effective mechanism in water management procedures for removing turbidity and contributing to the effectiveness of subsequent treatment processes such as sedimentation, filtration, and disinfection [107]. Therefore, coagulation and flocculation are reportedly some of the most commonly used methods for restoring palatability and improving the aesthetic appearance of turbid water due to their simplicity and efficacy [105]. Due to its ability to remove colloidal particles as well as bacteria that are also bound to them by causing colloidal particles to become destabilised, resulting in an increase in particle size for easier sedimentation, coagulation is considered an important step in the handling of drinking water [105-106]. Natural coagulants or chemical-based coagulants could be used to achieve coagulation and flocculation [105]. Natural coagulants have long been recognised for their use in traditional water purification, as evidenced by numerous historical documents cited. However, nowadays, aluminium salts, iron salts, and polymers (PACl, polyacrylamide, polyacrylic acid) are commonly used as synthetic coagulants and flocculants in water treatments [107]. Meanwhile, the imported chemicals for conventional water purification, such as aluminium salts and poly aluminium chloride, are prohibitively costly [106].

Furthermore, several studies have shown that using these compounds have health and environmental implications [107]. The negative effects of chemical coagulants on human health and well-being were first reported in the 1960s [108]. The presence of residual aluminium in alum-treated water has sparked controversy because it has been attributed to significant health problems, including the onset of Alzheimer's disease (AD) [109-112]. Unreacted chemical monomers and polymer by-products in water can also pose a health risk to humans [113]. One of the reported major issues that water treatment plants face is the difficulty of disposing high-volumes of sludge due to the aluminium content, residual aluminium accumulation in the treated water, the reaction of aluminium with alkalinity of the water and as such contributing to a large decrease in the pH of water, and its poor coagulating potential in cold water [106]. Due to the drawbacks of chemical coagulants, there is a need to explore other possible solutions for water clarity in order to reduce environmental risk and protect human health [105]. Natural coagulants and flocculants are gaining significant attention because they can eliminate chemical residues, allow the use of a variety of waste sources, reduce disease risk, and are readily biodegradable [107]. Plant-based natural coagulants are relatively safe [114], environmentally sustainable, and toxic-free [113] compared to a chemical coagulant. Moreover, natural coagulants have been shown to produce a sludge volume that is up to five times smaller than conventional coagulants, as well as a higher nutritional sludge content. Indirectly, the cost of sludge treatment and disposal is reduced, as well as the possibility to skip the pH adjustments making it a more sustainable choice [105].

Plant waste, such as peels and seeds, accounts for up to 50% of overall fruit weight and is usually non-edible. These vast proportions of waste are typically dumped into the environment due to their lack of economic appeal [105]. The mishandling of fruit waste may be harmful to environments due to possible leaching into soil and water bodies, resulting in more contamination [115]. Alternatives to synthetic polymers or alum include natural polyelectrolytes obtained from plants and animals, such as vegetable tannins and cactus mucilage, as well as chitosan [106]. To date, findings have suggested that nine fruit wastes could be used to treat turbid synthetic water, untreated surface water, and wastewater which are *Carica papaya* seeds, *Feronia limonia*, *Mangifera indica*, *Persea americana* seeds, *Phoenix dactylifera* seeds and pollen sheath, *Prunus armeniaca*, *Tamarindus indica* peels, *Citrus sinensis* peels, and *Hylocereus undatus* foliage [105].

Dragon fruit foliage may be used for the same purpose as *Cactus Latifaria* and *Opuntia*, and using natural coagulants specifically leads to global environmental technology efforts because the dragon fruit plant is abundant, harmless, and biodegradable. These findings have shown the ability of white dragon fruit (*Hylocereus undatus)* foliage to act as a natural coagulant in the treatment of concentrated latex effluent [116] palm oil mill effluent (POME) [126] and paint wastewater [127]. The elemental compositions of the dragon fruit foliage were compared to those of other natural coagulants namely; *Moringa oleifera*, and the *Cactus Opuntia*. It was observed that the foliage contained 43.1% carbon, 3.8% nitrogen, and 2.9% hydrogen. As a result, it was concluded that the foliage had a lot of promise as a natural coagulant for wastewater treatment, but it has been proposed that it may be used in the pre-treatment or primary stage prior to further treatment in the secondary stage by biological processes. Accordingly, dragon fruit has been shown to be a good source of natural coagulant in water treatment [106-107]. The pH of real water improved from 4 to 9, the turbidity removal of the dragon fruit foliage coagulant decreased [106]. The pH spectrum of 6 to 8 extracts displayed very low coagulation behaviours, while pH 4 was the most suitable pH for both examined extracts to conduct coagulation. In general, the pH value of finished water persisted within WHO (2011) guidelines at its initial pH of 6.4. Moreover, the mucilage content in *H. undatus* and its accessibility as coagulant have been analysed [107]. Mucilage are polysaccharides found in a variety of plants that expand when dissolved in water and take on a viscous consistency similar to gelatine [117]. They have been used in the treatment of contaminants from wastewater in both coagulant and flocculant roles, with removal quality of suspended solids (SS) ranging from quite low (around 26%) to very high (about 89-97%) [118-119]. Some parts of the *Hylocereus undatus* (white dragon fruit) such as the stem, leaf, and fruit, contain mucilage. Galacturonic acid, found in cactus mucilage, is the most common active coagulation agent, regardless of the species. Dragon fruit contains high levels of natural polymers such as galacturonic acid and proteins, which provide active sites for particle adsorption and aid in the coagulation process [105]. Mucilage's hydrocolloid properties are the foundation for its use as a bio-flocculant, so mucilage from the dragon fruit peel is a heteropolysaccharide with rheological properties that are useful [120]. As a result, the mucilage from the dragon fruit peel can be used to treat dye wastewater in a greenway.

FUTURE RECOMMENDATIONS

It can be seen that numerous studies done over the years on the applications of *Hylocereus spp* fruit as well as by-products in various industries. The pitaya species have been proven to be potentially useful as natural coagulating agents in latex waste water treatment, paint wastewater treatment as well as in the treatment of palm oil mill effluent (POME). Moreover, due to the presence of specific bioactive compounds in the fruit and its by-products, dragon fruit is also being employed in the food and beverage industry as natural antioxidants.

Environmental health has become a major issue in the recent decades due to the ever-growing levels of non-biodegradable and toxic chemical compounds being disposed of into the nature. Therefore, researchers in the oil and gas industry are looking into developing biosurfactants – surfactants which are formulated using natural compounds derived from plants and animals which makes them biodegradable, low toxicity levels, and high biocompatibility. As such, this makes the *Hylocereus spp* a highly potential plant species to be studied in developing the natural surfactants due to the presence of the specific bioactive compounds. Such research will be able to tackle a major issue present in the oil and gas industry – formation of water-in-oil emulsions [121]. Formation of emulsions has a negative influence on the production and transportation of oil and gas. Moreover, emulsions further impact the cost of transporting and pumping of crude oil, maintenance of the equipment due to corrosion, and the loss of catalyst [122-124]. These problems occur due to the high stability and viscosity levels of the emulsion formed. Thus, surfactants are required to stabilize the droplet interface by lowering the interfacial tension and adsorbing it at the oil and water interface. Typically, the emulsifiers used to overcome this issue are derived from fossil fuels; unfortunately, fossil fuels are toxic to both human and environmental health and are damaging towards the equipment used.

Up to date, there has been no research done investigating the potential application of *Hylocereus spp* in developing biosurfactants in the oil and gas industry. Hence, future studies can further investigate the role of dragon fruit and its applications with a broader research scope such as its involvement in the oil and gas industry.

CONCLUSION

Hylocereus spp is one of the most popular commercial and economically beneficial crops. This is due to its unique morphology, easily met requirements for their propagation and cultivation; such as the stem cutting technique and the crops resilience to extreme environmental conditions. Moreover, its nutritional contents have made it as “super food”, highly beneficial for health. In addition, the whole crop including the fruits and its by-products such as the peel have broad applications in numerous industries. However, there is still a lot more to be discovered about this unique plant species.

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