

Chapter

Secondary Metabolites of Edible Cacti (Cactaceae) from the South American Andes

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Abstract

The South American Andes hide countless cacti and are part of valuable Andean biodiversity. Within this large family of Cactaceae are edible cacti that are highly valued for their medicinal properties and used as edible fruits. In this review, we will make a description of the overall chemical composition, main phytochemicals found in some edible cacti of the Andean region such as sanky (*Corryocactus brevistylus*), pitahaya (*Hylocereus monacanthus*, *Hylocereus megalanthus*) and tuna or prickly pear (*Opuntia ficus-indica*). In addition, we will include its medicinal and therapeutic properties and its commercial applications and uses as a natural colorant.

Keywords: edible cacti, Andean region, phytochemicals, healthy properties, commercial applications

1. Introduction

Cactaceae are a large family of plants that prosper in desert and semidesert areas. These plants have been used by ancient civilizations for the treatment and cure of diseases [1]. In addition, they have been used as fodder (dairy cows) [2], medicinal (nutritional qualities and health implications) [3, 4], fruits and vegetables (prickly pear “tuna”, and dragon fruit “pitahaya”) [5–7] processed products (jams, syrups, concentrated juices, candies, wine, natural colorants, and others) [8, 9]. Cactaceae have been shown to provide significant health benefits because of their dietary fiber, flavonoids, hydroxycinnamic acids, betalains, carotenoids, terpenes, and tannins contents, that show health benefits such as anti-microbial and anti-parasitic, anti-proliferative and cytotoxicity and anti-inflammatory properties and inhibition of enzymes involved in carbohydrate catabolism (α -glucosidase and α -amylase) [10, 11].

Many of the native food fruits that grow in the Andean and Amazonian regions have generated much interest today due to the wide range of nutrients and bioactive

compounds they possess. Among edible fruits, we can find Cherimoya (*Annona cherimola* Mill), lucuma (*Pouteria lucuma* (Ruiz & Pav.) Kuntze), goldenberry or cape gooseberry (*Physalis peruviana* L.), saúco (*Sambucus peruviana* H.B.K.), pepino (*Solanum muricatum* Aiton), soursop (*Annona muricata* Linnaeus), asaí or açai (*Euterpe oleracea* Martius), camu-camu (*Myrciaria dubia* (H.B.K.) McVaugh), Inca peanut or sacha inchi (*Plukenetia volubilis* Linnaeus), sachatamate (*Solanum betaceum* (Cavanilles) Sendtner), guinda (*Prunus serotina*), granadilla (*Passiflora ligularis*), tumbo serrano or banana passion fruit (*Passiflora tripartite* var. *mollissima*), tuna or prickly pear (*Opuntia ficus-indica*), sanky (*Corryocactus brevistylus*), and pitahaya (*Hylocereus monacanthus*, *Hylocereus megalanthus*) [12–15].

The objective of this review is to compile the general chemical composition and bioactive phytochemicals of pitahaya, tuna or prickly pear and sanky, as well as the commercial applications. The aim of this paper is also to generate research interest in the valorization of edible cacti (Cactaceae) from the South American Andes and its by-products.

2. Pitahaya

Pitahaya, also known as pitaya or dragon fruit, (*Hylocereus* spp.) is an exotic tropical fruit that belongs to the *Cactaceae* family and *Hylocereeae* tribe [16, 17]. The pitahaya taxonomy is shown in **Table 1**; although it is native to Central and South America, it is currently grown for commercial purposes in Asian countries such as Vietnam, Malaysia, Thailand, and Taiwan [18, 19]. In South America, it is distributed across Venezuela and Bolivia, but the countries having a considerable production are Colombia, Ecuador, and Peru (**Table 2**) [18, 24]. In the Colombian territory, the cultivated hectares are distributed between Boyacá, Quindío, Santander, and Valle del Cauca [18]. In Ecuador, pitahaya is found in the provinces of Pichincha, Morona Santiago, and Loja [22], whereas in Peru, pitahaya is produced in Amazonas, San Martín, Lambayeque, and Junín [16].

The cactus plant of the pitahaya is a climbing, perennial, shrub-like plant that can grow up to 2 m. It is cultivated at an altitude of 500–1900 m above sea level, at an average temperature of 22°C and a relative humidity ranging from 70 to 80% [26].

Scientific name	<i>Hylocereus</i> spp.
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Caryophyllales
Family	Cactaceae
Tribe	Hylocereeae
Genus	Hylocereus
Species	<i>Hylocereus megalanthus</i> , <i>H. Hylocereus microcladus</i> Backeberg, <i>H. Hylocereus monacanthus</i> *

Adapted from Verona-Ruiz et al. [16]. *Some endemic species of South America.

Table 1.
Hylocereus spp. taxonomy.

Variety	Country	Region	Reference
<i>Selenicereus megalanthus</i>	Colombia	Valle del Cauca	[20]
<i>Hylocereus megalanthus</i>	Colombia	Fusagasugá	[21]
<i>S. megalanthus</i>	Ecuador	Morona Santiago	[22]
<i>S. megalanthus</i>	Peru	San Martín	[23]
<i>S. megalanthus</i>	Colombia	Valle del Cauca	[24]
<i>H. triangularis</i>	Peru	Huancavelica	[25]
<i>S. megalanthus</i>	Ecuador	Pichincha	[26]
<i>S. megalanthus</i>	Peru	Chachapoyas	[27]
<i>S. megalanthus</i> and <i>Hylocereus polyrhizus</i>	Colombia	Valle del Cauca	[28]
<i>H. megalanthus</i>	Peru	Cajamarca	[29]
<i>H. megalanthus</i>	Colombia	Ibagué	[30]

Table 2.
Locations of the different varieties of pitahaya are found in the Andean region.

The stems are characterized by their three wavy wings with horny scalloped margins. Each stem segment can grow up to 6 meters long [16]. The cladodes of the pitahaya cactus have 3–5 edges, contributing to its triangular shape. This plant grows wild on trees, rocks, logs, and walls, and is cultivated on trellises to support plant growth [18].

Pitahaya flowers are green on the outside, featuring interior white segments that are approximately 12 inches long and 9 inches wide. The stigma is lobed and green in color. Night-blooming pitahaya flowers open during the early morning and wither at dawn [16]. Pitahaya is characterized by being an ovoid berry 10–12 cm long and 7 cm wide [22]. The peel and pulp of some varieties can change colors, and the peel can vary from yellow to pinkish-red [17]. The fruit can weigh from 200 to 350 grams and contains approximately 650 seeds [18, 24].

Due to the great similarity in their morphological characteristics, different species of this family have been generically called “pitahaya.” This made its botanical classification more complex. Within this species, four genera stand out: *Stenecereus* sp., *Selenicereus* sp., *Hylocereus* sp., and *Cereus* sp. [18]. The species that is distinguished by its peels and pulp is *H. undatus*. This pitahaya has white pulp and red-pink peel, and it is the most popular variety worldwide [31]. *H. costaricensis* is a pitahaya with red pulp and peel, and it is also known as *H. polyhizus* [16]. Finally, *H. megalanthus* or *Selenicereus megalanthus* is a pitahaya with yellow peel and white pulp (**Figure 1**), being the most highly produced variety in South America [18].

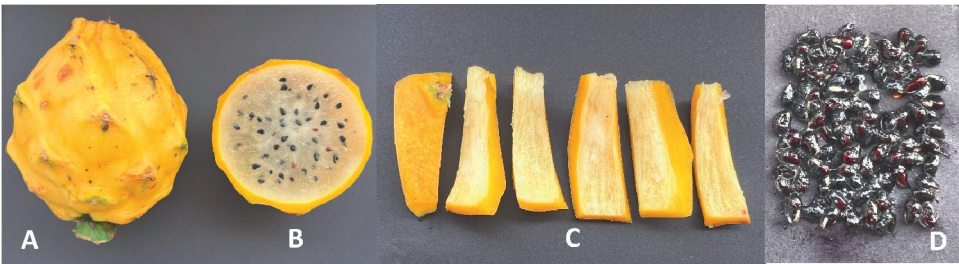


Figure 1.
Major parts of pitahaya with yellow peel fruits. (A) Fruit, (B) mesocarp, (C) peel, and (D) pitahaya seeds (wet).

Pitahaya is preferred by consumers because of its unique flavor, shape, and pulp color. In addition, it is famous for its low caloric value because it contains small amounts of carbohydrates (9.20 g per 100 g of edible pulp) [16]. In European and Asian markets, pitahaya is categorized as an exotic fruit because of the appearance of its peel and the bittersweet taste of its pulp. In the United States and various European countries, the pitahaya pulp is also in demand as a food ingredient or as a natural food colorant [17]. Conversely, in Malaysia and Indonesia, pitahaya is usually marketed as jams and sweets. In the province of Guangxi (China), red pitahaya is used to make wine [31].

Pitahaya is often described as a sweet fruit; however, this depends on its variety. The yellow pitahaya [*Selenicereus megalanthus* (k. Schum. Ex vaupel) moran] cultivated in Colombia has an acidic and sweet taste owing to the high content of soluble solids, while its organoleptic characteristics are more appealing than other similar species of the genus *Hylocereus* [23].

The betacyanin content in both the pulp and peel usually stands out in this fruit. Similarly, the presence of lycopene, vitamin E, beta carotene, total polyphenols, tannins, and antioxidant compounds has been reported [16, 31]. Essential fatty acids, led by linoleic acid (64.5%), oleic acid (14%), and palmitic acid (14.4%) have been found in the seeds [18, 31]. The beneficial effects of pitahaya range from relief of stomach problems to the amelioration of endocrine disorders and improvements in the digestive system function. The most recognized benefit of pitahaya is the antioxidant capacity attributed to its seeds, the most important antioxidant being linoleic acid because it works as an antioxidant buffer, captures cholesterol, producing a cardiotonic effect [16, 18]. Likewise, linoleic acid has been shown to reduce dyslipidemia and promote wound healing in diabetic rats [18].

2.1 Overall chemical composition

Pitahaya is a sweet-tasting fruit with a pulp of different colors; its weight can reach up to 700 g, with diameters of approximately 15–10 cm. According to Mercado-Silva [32], the pulp color varies between white and red, contains black seeds, and represents 60–80% of the total weight of the fruit depending on the variety. **Table 3** summarizes the nutritional composition of the pulp in three different commercial species. The *H. undatus* variety was added to compare the characteristics of a species outside the Andean region. The moisture (85–89%) and protein content (0.5–0.6 g)

Component	<i>Hylocereus undatus</i> (Mexico)	<i>Selenicereus maegalanthus</i> (Peru)	<i>Selenicereus megalanthus</i> (Colombia)
Water (%)	89	89	85
Proteins (g)	0.5	0.5	0.6
Fats (g)	0.1	0.1	0.4
Carbohydrates (g)	NE	9.1	13
Dietary fibers (g)	0.3	0.3	0.77
Vitamin C (mg)	25.0	8.0	—
Ash (g)	0.5	0.5	0.3

Adapted from Cañar et al. [24], Mercado-Silva [32], and Obregón-La Rosa et al. [23].

Table 3.
Nutritional composition of 100 g of pulp from different species of pitahaya.

do not differ between the varieties. Similarly, the ash content varies from 0.3 g to 0.5 g. However, the Colombian yellow pitahaya had a higher percentage of dietary fiber (0.77 g) when compared with previous reports. This fruit is widely famous for its vitamin C content, which is involved in the formation of collagen, red blood cells, bones, and teeth [20]. However, the table shows that the red variety (*H. undatus*) stands out for its vitamin C content when compared with the yellow variety of the Andean region (*Selenicereus megalanthus*).

Different studies show that the fresh weight of pitahaya increases in direct proportion to the development of the fruit, and the content of soluble solids depends on the ripening stage [22, 32–34]. Following the physicochemical evaluation of pitahaya grown in Morona Santiago (Ecuador), Sotomayor et al. [22] determined that the percentage of peel decreases from 55.9% to 33.4%, while that of the pulp increases from 44.1% to 66.6% between maturity stages 0 and 6. In addition, the flavor of the pitahaya will depend on the maturity during its harvest due to the degradation of polysaccharides, an important factor that determines the concentration of carbohydrates. According to Ochoa Velazco [17], the total soluble solids (TSS) that predominate in pitahaya are glucose and fructose.

The content of TSS in pitahaya is variable (14–16°Brix) and the titratable acidity is usually low (0.2–0.35 m% malic acid/100 g of fresh weight) [32]. In a study conducted by Chauca and Chávez [27], pitahaya from Chachapoyas had a TSS value of 17.4°Brix and an acidity of 0.20% citric acid/100 g fresh weight. Similarly, pitahayas collected from the Cauca valley presented a TSS value of 14.3°Brix and an acidity of 1.35 mg citric acid/100 g fresh weight [24]. Torres Grisales et al. [20] obtained values of 17.7°Brix and titratable acidity of 0.20% citric acid in the *S. megalanthus* variety harvested in the province of Valle del Cauca. Although, the TSS does not determine consumer acceptability, it is an indicator of sweetness, which results from the combination of soluble sugars and organic acids. A TSS combination with high acidity is associated with a better flavor, making the fruit very appealing to consumers [19].

2.2 Bioactive phytochemicals

The fruit of the pitahaya, especially the mesocarp, has a high nutraceutical value and is considered a functional food as it contains healthy bioactive compounds [19]. The pitahaya pulp not only contains sugars and acids but also fiber, vitamin C, pectin, and different pigments [35]. In samples of *S. megalanthus* harvested in Peru, the vitamin C content ranged between 7 and 9 mg/100 g of pulp [23]. Torres Grisales et al. [20] obtained similar results (8 mg ascorbic acid per gram of dry matter) for pitahaya pulp from Valle del Cauca. The pitahaya peel and seeds were also analyzed, showing higher values. The seeds stand out in the results, containing up to 22.0881 mg ascorbic acid per gram of dry matter. Some studies indicate that the content of vitamin C in varieties outside the Andean region is higher (Table 4). Thus, the content of vitamin C in the species *H. monacanthus* collected in Fortaleza (Brazil) was found to be 107.02 mg/100 g [36]. Similarly, *H. undatus* from Sao Paulo (Brazil) presented 45.79 mg of vitamin C/100 g [37].

Polyphenols (Table 4), carotenoids, tocopherols, and glucosinolates are usually found in fruits and vegetables. A chemoprotective effect has been attributed to these compounds to combat oxidative stress, as well as anti-inflammatory properties benefiting human health [35, 36]. In the case of pitahaya, the total content of phenolic compounds in fruits of *H. megalanthus* from Cajamarca was 16.17 mg of gallic acid equivalent (GAE) per 100 g of pulp [29]. Likewise, these components were evaluated

Species	Location	Bioactive compounds or micronutrients	Concentration	Reference
<i>Selenicereus megalanthus</i>	San Martín, Peru	Vitamin C	8.00 mg/100 g	[23]
<i>Hylocereus megalanthus</i>	Cajamarca, Peru	Total phenolic compounds	16.17 mg GAE/100 g	[29]
<i>H. megalanthus</i>	Fusagasugá, Colombia	Total phenolic compounds	59.10 mg GAE/100 g	[21]
<i>S. megalanthus</i>	Valle del Cauca, Colombia	Total phenolic compounds	1580 mg GAE/100 g	[20]
<i>S. megalanthus</i>	Chachapoyas, Peru	Total phenolic compounds	2.01 mg GAE/g	[27]
<i>H. megalanthus</i>	Ibagué, Colombia	Total phenolic compounds	7.8 mg GAE/100 g	[30]

Table 4.

Bioactive compounds are found in different varieties of pitahaya in the Andean region.

to determine the inhibitory effects on α -amylase and α -glucosidase as a possible complementary therapy for diabetes mellitus. The IC_{50} value in the case of α -amylase was 8692.4 μ g/mL and there was no inhibitory effect on α -glucosidase. According to the authors, the antidiabetic effect of the fruits of the *Hylocereus* family is not a result of their ability to inhibit digestive enzymes, but rather a result of their ability to improve insulin resistance and increase gene expression levels of the fibroblast growth factor 21 receptors [29].

In a study by Mejia et al. [21], the phenol content for the *H. megalanthus* variety from Fusagasugá (Colombia) was 59.1 mg gallic acid (GAE)/100 g fresh weight. Compared with the other exotic Colombian fruits assessed, pitahaya showed a moderate phenol content (80 > GAE/100 g). In addition, the antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and the 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) methods, as well as the ferric reducing antioxidant power (FRAP) assay relative to fresh weight basis. The results for this fruit were 177.1 μ mol of Trolox Equivalent (TE)/100 g, 323.8 TE/100 g, and 811.2 μ mol of Fe^{+2} /100 g, respectively. Additionally, the authors evaluated the elimination capacity of reactive nitrogen species. Samples of *H. megalanthus* exhibited a potent peroxyl radical scavenging activity with a value of 2999.77 μ mol of TEs/g.

Torres Grisales et al. [20] assessed the content of phenols in all parts of pitahaya and showed that the seeds and the peel contain the highest amount of these compounds. A total of 1580 mg GAE/100 g dry matter were found in the seeds. Additionally, the authors analyzed the antioxidant capacity of phenols extracted from the pulp, peel, and seeds using the ABTS and DPPH assays. High levels of antioxidant activity were shown in all parts of the fruit. Nonetheless, the higher antioxidant activity was found in the seeds, with values of 79.2% and 96% for ABTS and DPPH assays, respectively.

In contrast, the amount of phenolic compounds in the peel and pulp of lyophilized yellow pitahaya (*S. megalanthus*) from Chachapoyas was also determined. In this study, the lowest values in peel and pulp were obtained, with 1.50 and 2.01 mg GAE/g of the sample, respectively. Similarly, the antioxidant activity was lower than expected by the authors, with values of 8.15 and 7.7 μ mol TEs/g in pulp and peel, respectively [27].

Component	g/kg of oil
Fatty acid	182 ± 11
Palmitic acid	3 ± 1
Palmitoleic acid	49 ± 3
Stearic acid	239 ± 16
Oleic acid	45 ± 6
Cis-11-vaccenic acid	466 ± 42
Linoleic acid	18 ± 2
Arachidic acid	182 ± 11

Adapted from Villalobos et al. [38].

Table 5.
 Fatty acid profile of oil extracted from red pitahaya seeds (g/kg of oil).

The oil content and characteristics of *Hylocereus* seeds have been extensively studied. As mentioned above, pitahaya seeds have a high content of linoleic acid, which represents between 1% and 2% of the total weight of the fruit [18, 31, 35]. According to Villalobos-Gutiérrez et al. [38], the predominant saturated fatty acids in pitahaya seed oil are palmitic acid, stearic acid, and arachidic acid, which only represent 249 g/kg of total fatty acids. **Table 5** summarizes the amount of total fatty acids found in the red pitahaya variety (*Hylocereus* sp. [Weber] Britton & Rose) from Nicaragua.

Torres Grisales [20] observed that pitahaya seeds have a greater ability to accelerate peristalsis by increasing the amount of feces produced by 55% when compared with biomodels fed a diet based on sunflower seeds. The laxative capacity of the other parts of pitahaya was also evaluated; however, the peel decreased the production of feces. It is important to mention that the consumption of pitahaya pulp and seeds promotes its output, although with a less solid appearance. This could be related to the passage of stool. According to Verona-Ruiz [16], the oligosaccharides present in the pulp serve as a possible source of prebiotics and stimulate the growth and/or activity of specific bacteria in the colon.

2.3 Commercial applications

Numerous studies on different varieties of pitahaya (*H. undatus*, *Hylocereus polyrhizus*, and *H. megalanthus*) have shown the variety of benefits that can confer to human health [19, 39–41]. The peel can be used as raw material for the extraction of pectin, betacyanins, and dietary fiber [42]. In addition, it is used in food packaging and edible coating [43]. The pitahaya pulp has been shown to have nutraceutical properties and can be used to prepare fermented beverages. This would increase the content of phenolic compounds [16, 17, 31]. Finally, pitahaya seeds and their high content of unsaturated fatty acids can be used in the food, cosmetic, or pharmaceutical industry. The oligosaccharides present in the seeds is a potential source of prebiotics with a demonstrated ability to stimulate the growth of lactobacilli and bifidobacteria [16, 35].

Within the region, two studies have been conducted on the production of drinks based on pitahaya pulp. Enriquez Paredes and Ore Areche [25] obtained a functional drink made with malt from *Amaranthus caudatus* L. (kiwicha) and pulp from *Hylocereus triangularis*; both fruits were collected in Huancavelica (Peru). This drink was

Ingredient	Amount
Water	3 L
Pitahaya pulp	1 L
Malted kiwicha flour	100 g
Sugar	200 g
Citric acid	4.50 g
Carboxymethylcellulose	3.70 g

Taken from Enriquez Paredes and Ore Areche [25].

Table 6.
Composition of a drink based on *Amaranthus caudatus* L. and pulp of *Hylocereus triangularis*.

	BHC	BH 4%	BH 6%	BH 8%
Phenolic content (mg GAE/100 mL)	33.90 ± 1.27	100.92 ± 2.10	117.59 ± 0.84	112.86 ± 0.11

Taken from Castro Carranza et al. [44].

Table 7.
Phenolic content of the drink based on *Hylocereus undatus* and vegetable extracts.

successful in a panel of 20 specialists, and its formulation is presented in **Table 6**. The drink reached a pH of 3.7 and 11.50°Brix, with a lack of molds, yeasts, and coliforms. The authors highlighted the protein content of the drink (8.53%), which is highly nutritious and suitable for consumption.

In the study conducted by Castro Carranza et al. [44], a functional drink was developed based on pitahaya (*Hylocereus undatus* (Haw.) Britton & Rose) with extracts of lemon verbena (*Cymbopogon citratus*) and basil (*Ocimum tenuiflorum*). The fruit and leaves for this project were collected in the province of Manabí, Ecuador. The drink was elaborated through the incorporation of the vegetable extracts in different percentages (4, 6 and 8%) to the pitahaya juice. These percentages were reached after mixing the vegetable extracts at a 1:1 volume-volume ratio. The authors determined the total phenolic content of drinks prepared with different percentages of extracts, as shown in **Table 7**.

The results showed that the addition of *C. citratus* and *O. tenuiflorum* extracts can increase the concentration of phenolic content of drinks based on *H. undatus*, thereby enhancing its antioxidant properties. The authors believe that elaborating foods with improved functional properties is possible using the studied fruits to improve the health and quality of life of consumers [44].

3. Tuna or prickly pear

O. ficus-indica (L.) Mill. is a species of the Cactaceae family, genus *Opuntia*, and is commonly known as prickly pear, cactus pear, Barbary fig, Indian fig, nopal, or tuna [45]. The complete taxonomic lineage is shown in **Table 8**. Prickly pear is distributed throughout the American continent, from southern Canada to Patagonia. There are no exact records of its origin, but it is believed to be native to Mexico [35, 46]. Its domestication is centered in arid and semi-arid climates of the regions of Mexico

because it has special adaptation mechanisms and a high biomass production capacity. This allows it to grow in harsh conditions, such as high temperatures and nutritionally poor soils. However, prickly pear is also cultivated in tropical and subtropical America and Mediterranean countries [46, 47].

Currently, Mexico is the largest producer of prickly pears in the world, with a production of 356 thousand tons/year [48]. The largest production areas are Zacatecas, Puebla, and Hidalgo, where the harvest takes place from July to September [49]. Another country that stands out for the production of prickly pears is Peru, where up to 100,000 tons of prickly pears are cultivated, with the larger areas of Ayacucho (20%), Huancavelica (15%), Arequipa (15%), Lima (14%), and Apurímac (8%) dedicated to its cultivation [50]. Moving to the Andean region, the next largest producer is Chile, with approximately 800 ha dedicated to the production of red, green, and orange prickly pears. These production areas are concentrated in Metropolitana, Valparaíso, and Coquimbo [51].

Like all cacti, *prickly pear* is a bushy, succulent, branched plant composed of joints or fleshy segments that reach an average height of 3–6 m and have a stem or trunk 60–150 cm wide [52]. The *O. ficus-indica* species is a shrub/arborescent plant that can reach up to 5 meters in height. The root system is fleshy and branched; it develops horizontally and laterally, and can reach 10–15 m from the base of the plant [53]. Its stem is well defined, dark brown, green or gray in color and cylindrical in shape, and is 45 cm long and 20 cm in diameter. Its cladodes are generally elliptical or rhomboid 30–40 cm long and 20–25 cm wide [54].

The fruit is spherical, cylindrical, or elliptical in shape; it can measure 6–10 cm in length and 4–7 cm in diameter. Characterized by being juicy and sweet, its color varies between yellow and red, while the pulp has the color of the peel. The size of the fruit is determined by the number of fertilized and aborted seeds. Its shape is ovoid and fleshy, and the fruit has a leathery pericarp on which tufts of glochids are found [47, 54]. The weight of the fruit varies between 100 and 200 grams, of which 30–40% represents the weight of the peel. During the initial stages of development, the peel is green and can change to greenish-white, yellow, orange, red (**Figure 2**), purple, purplish-yellow, or even violet or dark brown, depending on the growing variety [55]. At present, two

Scientific name	<i>O. ficus-indica</i>
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Caryophyllales
Family	Cactaceae
Subfamily	Opuntioideae
Tribe	Opuntieae
Genus	<i>Opuntia</i>
Subgenus	<i>Opuntia</i>
Species	<i>O. ficus-indica</i> (L.) Mill., 1768

Taken from Guerrero-Beltrán and Ochoa-Velasco [46].

Table 8.
Opuntia ficus-indica taxonomy.

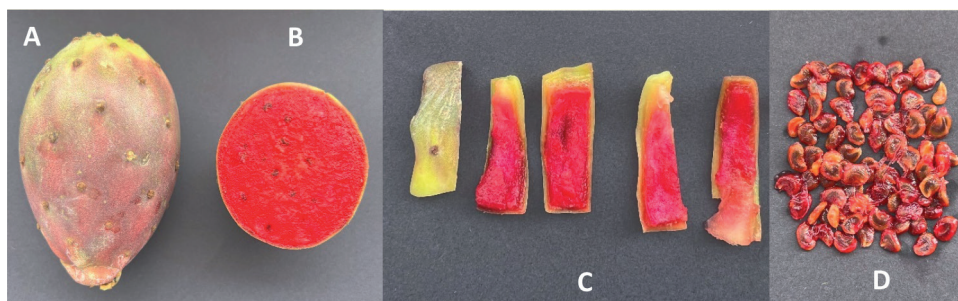


Figure 2.

Major parts of tuna or prickly pears with red peel fruits. (A) Fruit, (B) mesocarp, (C) peel, and (D) tuna seeds (wet).

parts of the plant are used as food, the fruits (tuna) and the cladodes (nopal). Prickly pears can be eaten fresh, after drying in the sun, or in jams. In addition, nopal is consumed mainly in Mexican regions as an ingredient present in salads [56, 57].

This plant is characterized by its richness in polyphenols, vitamins, polyunsaturated fatty acids, and amino acids. The identified compounds and their derivatives have been shown to possess relevant biological activities, including anti-inflammatory, antioxidant, hypoglycemic, antimicrobial, and neuroprotective activities, among others [35]. *Opuntia* flowers come in various colors, but the color progression during bloom ranges from white to yellow and can turn to red, orange, pink, and peach. The flowers are ancillary, also considered by-products because they are generally discarded after the fruit is separated. There is evidence that the floral compounds of *Opuntia* are phenolic pigments and betalain [58].

Conversely, plants of the genus *Opuntia* are used for carminic acid production. This acid is extracted after grinding and desiccating the females of a parasitic worm called “cochineal,” which grows on the surface of the succulent branches of these plants [59]. Carmine red dye is used in the food industry, according to European law, as (E-120). Peru produces 90% of the world’s cochineal, whereas the Arequipa region accounts for 70% of the national production. Peru produces 1986 tons of dry cochineal per year [56, 59].

3.1 Overall chemical composition

At present, prickly pears can be found in different colors and shapes, and with or without thorns, but there are no obvious differences between traditional and modern cultivars [52]. Their difference lies in the amount of betalains and betaxanthins found, depending on the prickly pear variety [46]. According to Assunção Alves et al. [47], in case of minimal differences between a red, orange, or green prickly pear, these may be due to the cultivation conditions, the state of maturity during harvest, or the analytical methodology used.

According to the information collected by Corzo-Rios et al. [35], prickly pear contains approximately 85% water, 15% sugar, 0.3% ash, and less than 1% of protein. This is similar to that reported by Medina et al. [56] and Gonçalves Albuquerque et al. [53] in red and green prickly pears from Spain and Mexico, respectively. The moisture content varies between 82% and 92%, and the protein and fat content does not exceed 2% and 1% of the total weight, respectively (Table 9). Prickly pears do not have a distinctive aroma, but the pulp is very sweet and the sugar components are mainly glucose

Component	Orange prickly pear (Argentina)	Green prickly pear (Mexico)	Red prickly pear (Argentina)
Moisture (%)	81.29	91.10	85.43
Ash (%)	0.53	5.40	2.34
Total soluble solids (%)	14.78	—	10.16
Proteins (%)	1.56	1.70	1.41
Lipids (%)	0.35	0.10	0.22
Fibers (%)	—	1.50	—

Taken from Valero-Galván et al. [60] and Romero et al. [61].

Table 9.
 Physicochemical and nutritional composition of *Opuntia ficus-indica* (L.) Mill. pulp.

and fructose, whose concentration varies from 10 to 17°Brix [52]. In addition, the prickly pear pulp is characterized by a water activity between 97.2% and 99.3%, a pH of 5.2–5.5, and a titratable acidity (% citric acid) that ranges from 0.001 to 0.003 [60].

It is important to highlight the potential of the seeds and peel of the prickly pear. The seeds are distributed within the pulp and constitute between 30% and 40% of the fruit's wet weight. However, neither the seeds nor the peel is used despite being important sources of fatty acids, vitamins, polyphenols, flavonoids, tannins, and fiber [35]. The seeds (6.77 g/100 g dry weight) have been reported to have up to seven times the oil content of the pulp [53]. Besides, Medina [56] informed that the fiber content in the prickly pear's peel varies between 4.86 and 5.65 g/100 g dry weight. These results were obtained from orange and green prickly pears in different regions of Mexico. Likewise, these authors report that the peel and the seeds contain cellulose (71.4% and 83.23% of the total fiber). This is in line with the study conducted by Hernández-Carranza et al. [48] using red prickly pear peel, in which cellulose (34.64% dry weight) predominated in the total dietary fiber.

Different studies compiled by Cota-Sánchez [52] have shown that *Opuntia* fruit is a good source of minerals, specifically calcium, magnesium, potassium, and phosphorus. According to Medina [56], both calcium and potassium are the most predominant, with 26.30 and 158.30 mg/100 mg, respectively. This agrees with the study by Guerrero-Beltrán & Ochoa-Velasco [46], which assessed the chemical composition of prickly pears of different colors (Table 10). Potassium was the most abundant mineral, with the exception of the purple prickly pear (19.6 mg/100 g) in each variety, and phosphorus was much higher in green prickly pear when compared with the others (32.5 mg/100 mg).

Previous studies have shown that *Opuntia* fruits contain ascorbic acid, which ranges from 20 to 40 mg/100 g of fresh weight. In a study conducted by Guerrero-Beltrán and Ochoa-Velasco [46], the vitamin C content was also assessed, with results ranging from 20 to 24.1 mg/100 g. In a study by Medina [56], green and orange prickly pears from Tenerife (Spain) only yielded 17.1 and 17.2 mg/100 mg, respectively. Vitamins are not only found in the pulp but also fat-soluble vitamins (alpha, beta, and delta tocopherols, beta carotene, and vitamin K1) found in prickly pear seed oils [53].

In a study conducted by Jorge and Troncoso [62] on red prickly pears collected in Huancavelica (Peru), the vitamin C content was 36.1 mg/100 g. Similarly, Monroy-Gutiérrez et al. [63] evaluated different varieties of prickly pears and observed that

Minerals	Red prickly pear	Orange prickly pear	Purple prickly pear
Calcium	12.80	35.8	13.2
Iron	0.40	0.20	11.5
Magnesium	16.1	11.8	11.5
Sodium	0.6	0.90	0.50
Phosphorus	32.8	8.5	4.9
Potassium	217.0	117.7	19.6

Taken from Guerrero-Beltrán and Ochoa-Velazco [46].

Table 10.
Chemical and nutritional composition of prickly pears of different colors (mg/100 g).

Variety	Evaluation days								
	0	3	6	9	12	15	18	21	24
Red prickly pear “Rojo Pelón”	37.5	28.1	33.9	25.7	25.8	29.3	29.8	42.5	38.9
Red prickly pear “Liso Forrajero”	19.7	16.0	19.4	21.6	16.9	24.7	—	—	—

Taken from Monroy-Gutiérrez et al. [63].

Table 11.
Vitamin C content in red prickly pear cultivars (mg/100 mg).

the vitamin C content in the cultivars “Rojo Pelón” and “Liso Forrajero” (both red prickly pears) ranged from 42.54 to 16.00 mg/100 mg, where the highest value was presented 21 days after evaluation in the “Rojo Pelón” variety (**Table 11**).

3.2 Bioactive phytochemicals

Different studies indicate that all parts of *O. ficus-indica* are rich in polyphenols, flavonoids, and phenolic acids. This includes pulp, seeds, peel, flowers, and cladodes, with the pulp having the highest amount of bioactive compounds [35, 53, 58, 60, 64]. According to a report by Gonçalves Albuquerque et al. [53], the method most widely used to assess phenolic and polyphenolic antioxidants is Folin-Ciocalteu, although results may present considerable differences between studies, ranging from 5.54 to 1000 mg GAE/100 g of pulp. About phenolic compounds, quercetin is the most abundant component in prickly pear pulp, followed by isorhametin-3-rutinoside [55].

When analyzing green and orange prickly pears from the island of Tenerife (Spain), Medina [56] found that the phenol content in pulp was 45.0 and 45.4 mg/100 mg, respectively. This study also determined that one portion of *O. ficus-indica*, regardless of color, represents only 68% of the recommended total phenol intake per day. Similarly, Monroy-Gutiérrez et al. [63] evaluated the content of phenols in the pulp of red prickly pears from the Zacatecas region (Mexico). The authors observed that the phenol content in both varieties decreased during the evaluation period (**Table 12**), with the higher phenol content found in the variety “Rojo Pelón” from the beginning of the study (30.32 mg GAE/100 g). According to these authors, this is a consequence of the environmental conditions (temperature, relative humidity, and light), as well as the crop nutrients and the pre and post-harvest handling.

Variety	Evaluation days								
	0	3	6	9	12	15	18	21	24
Red prickly pear “Rojo Pelón”	30.3	15.7	16.0	12.5	14.2	13.7	13.6	18.2	17.8
Red prickly pear “Liso Forrajero”	6.3	5.8	5.6	4.6	4.7	5.1	—	—	—

Taken from Monroy-Gutiérrez et al. [63].

Table 12.
 Total phenol content in red prickly pear cultivars (mg GAE/100 g).

Variety	Pulp		Peel		Seeds	
	Red prickly pear	Green prickly pear	Red prickly pear	Green prickly pear	Red prickly pear	Green prickly pear
Total phenolic content (mg GAE/g)	3.62	5.00	4.32	4.34	4.30	2.93
Total flavonoids (mg catechin equivalents [CE]/g)	3.14	3.58	3.18	3.40	3.10	3.17
DPPH (mmol TE/g)	7.74	6.74	7.90	6.87	8.08	7.08
FRAP (mmol TE/g)	1.38	2.03	5.18	7.37	0.80	2.08
ABTS* (mmol TE/g)	11.87	16.33	16.42	17.65	14.19	17.18

Adapted from Valero-Galván et al. [60].

Table 13.
 Phytochemical profile and antioxidant capacity of commercial varieties of prickly pears (red and green).

In the study conducted by Valero-Galván et al. [60], the content of total phenols in pulp was higher than in the peel and seeds while the content of flavonoids was higher in the peel than in the pulp or seeds (**Table 13**). Likewise, the antioxidant capacity determined by DPPH was similar among the three types of tissues. However, the antioxidant activity determined by the ABTS assay was higher in the seeds and peel than in the pulp. In contrast, the results obtained by the FRAP assay showed higher antioxidant activity in the peel than in the pulp and the seeds.

The antioxidant capacity of prickly pear may be due to one or more components, but a synergistic effect is also possible. A study by Gonçalves Albuquerque et al. [53] indicates that prickly pear extracts have higher antioxidant activity than other fruits such as pears, apples, grapes, oranges, grapefruits, and tomatoes. Furthermore, compared with other *Opuntia* species, prickly pear has the lowest content of polyphenols and flavonoids but the highest antioxidant activity. Flavonoids are especially efficient antioxidants owing to their ability to inhibit pro-oxidative processes on DNA, proteins, and lipids, and to prevent the generation of stable radicals [55, 61, 63].

Monroy-Gutiérrez et al. [63] also analyzed the antioxidant capacity over time in red prickly pears, with results similar to previous studies. As days go by, the antioxidant activity decreased in all varieties (**Table 14**). The authors pointed out that *Opuntia* fruits have the moderate antioxidant capacity, which could be directly associated with the fruit pigment content and the growing conditions. This could be observed in the study conducted by Ordoñez et al. [64] on prickly pears collected in Huánuco (Peru), which showed different antioxidant capacities between the yellow

Variety	Evaluation days								
	0	3	6	9	12	15	18	21	24
Red prickly pear “Rojo Pelón”	0.51	0.52	0.50	0.44	0.44	0.44	0.46	0.51	0.53
Red prickly pear “Liso Forrajero”	0.42	0.42	0.42	0.39	0.39	0.39	—	—	—

Taken from Monroy-Gutiérrez et al. [63].

Table 14.
Antioxidant capacity in red prickly pear cultivars expressed in vitamin C equivalents (mg/g).

and purple peel varieties. The peel of purple prickly pear (18.50 mg/mL) presented greater antioxidant activity against the radical DPPH compared with the remaining tissues of the yellow prickly pear (16.73–27.99 mg/mL). In contrast, Jorge and Troncoso [62] found that the antioxidant capacity was provided by vitamin C, its contribution is greater than 50% of the total antioxidant capacity of the prickly pear.

Prickly pears have pulps and peels of different colors. These can be pale green, yellow, orange, magenta, red, and red-purple, indicating that these varieties have different pigments [46]. Betalains are water-soluble pigments that give the red-purple (betacyanins) and yellow (betaxanthins) colors to the fruits of several cactus species, such as *Opuntia* sp., *H. polyrhizus*, or *Myrtillocactus geometrizans* [65]. The concentration of these pigments is responsible for the color variation in prickly pears. In contrast, the pale green pigments are the result of chlorophylls. Betaxanthins include indicaxanthin, miraxanthin, portulaxanthin, and vulgaxanthin. In addition, plant betacyanins include betanin, isobetanin, neobetanin, and probetanin [46].

A study conducted by Guerrero-Beltrán and Ochoa-Velasco [46] compared three prickly pears of different colors. While their nutritional composition differed slightly from each other, the concentration of β -carotene in green prickly pear (0.5 mg/100 g) and orange prickly pear (2.3 mg/100 g) was highlighted, as well as the content of betanin in purple prickly pear (100 mg/100 g). Similarly, a study by Fernández-López et al. [55] assessed the content of betacyanins (15.2 mg betanin/100 g fresh fruit) and betaxanthins (25.4 mg indicaxanthin/100 g of fresh fruit) in red peeled prickly pears collected in Murcia (Spain). Valera-Galván [60] reported the betacyanin and betaxanthin content in green and red prickly pears. The pigment content was found to be higher in the fruit pulp, in contrast to the peel, with the concentration being greater in red prickly pears. However, there were no statistical differences between the antioxidant capacities of both varieties.

Monroy-Gutiérrez et al. [63] compared the content of betanins and indicaxanthins in two varieties of red prickly pear. The concentration of betanin (red-violet) was higher in the “Rojo Pelón” variety and increased during the evaluation days. The same was observed in said variety for indicaxanthin, starting at 9.52 mg/100 mg, and increasing to 19.91 mg/100 mg after 24 days of evaluation. Conversely, the concentration of both pigments in the “Liso Forrajero” variety decreased until day 15 (Table 15). According to Ortega-Hernández et al. [66], it is possible to increase the content of betalains, ascorbic acid, and phenolic compounds in prickly pears using UVB light and inflicting wounds in the plant tissue. This could explain the higher amount of betanin found in the “Rojo Pelón” variety. Caused by the red or purple coloration of these varieties, it was not possible to assess the chlorophyll and total carotenes content.

According to Cota-Sánchez [52], prickly pear seeds are rich in minerals and sulfur-containing amino acids. Additionally, the composition of fatty acids in *O. ficus-indica* seeds can improve food properties and be used as seasonings in

Pigment/variety	Evaluation days								
	0	3	6	9	12	15	18	21	24
Betanin									
Red prickly pear “Rojo Pelón”	12.6	14.6	17.9	15.6	16.7	17.4	16.7	19.1	22.2
Red prickly pear “Liso Forrajero”	7.9	5.5	7.7	11.8	6.9	7.4	—	—	—
Indicaxanthin									
Red prickly pear “Rojo Pelón”	9.5	13.6	13.3	14.1	18.1	21.7	11.6	11.2	19.9
Red prickly pear “Liso Forrajero”	8.8	9.2	8.5	9.8	4.9	7.5	—	—	—

Taken from Monroy-Gutiérrez et al. [63].

Table 15.
 Betanin and indicaxanthin content in red prickly pear cultivars (mg/100g).

Fatty acid profile	Orange prickly pear	Red prickly pear
C14:0	—	1.09
C16:0	25.08	22.74
C18:0	7.14	5.22
C18:1 n-9	22.61	18.81
C18:2 n-6	28.77	28.21
C20:0	—	1.22
C18:3 n-3	18.20	17.12

Taken from Romero et al. [61].

Table 16.
 Fatty acid profile in prickly pear seeds with orange and red peel.

culinary art. Corzo-Rios et al. [35] pointed out that the lipids present in *Opuntia* cladodes are palmitic, oleic, and linoleic. Romero et al. [61] was able to identify and quantify the fatty acid profile in orange and red prickly pears, where linoleic acid stood out (28.77 and 28.21 mg/100 g in orange and red prickly pears, respectively) (Table 16).

3.3 Commercial fruit application

The *O. ficus-indica* fruit is valued for its sweet and slightly sour taste. Different food products such as jams, jellies, nectars, dehydrated fruits, syrups, liqueurs, wines, and vinegars can be made from prickly pear [53]; however, this plant also has alternative uses in the Andean region. In Bolivia, prickly pear is used to treat heat stroke, sunburn, yellow fever, and gastritis. In Colombia, anti-inflammatory infusions are prepared from the leaves. Used in poultices, *O. ficus-indica* can relieve skin irritations or remove swellings. In Peru, fresh fruit is used to treat hair loss and diabetes [67].

Several biological activities have been reported for *Opuntia*; these encompass potential applications in health and nutrition. Prickly pear extracts are used for the treatment of diabetes, cholesterol, and immune diseases. Additionally, the extracted polysaccharides can protect the liver from organophosphate pesticide damage. The antioxidant capacity of betalains present in prickly pear can prevent ovarian and cervical cancer [35, 52]. These nutritional benefits increase the interest in making products from prickly pear.

The production of drinks or juices is the first step in the manufacture of other processed products, although heat treatment is usually a determining factor. The alteration of the sensory or nutritional characteristics usually occurs in products based on prickly pear or other fruits [46]. Nonetheless, Laguna Yanchaguano et al. [68] obtained a drink based on prickly pear and passion fruit (*Passiflora edulis*) collected in Ecuador with a high degree of acceptability. This was achieved by evaluating different concentrations of both fruits. According to this study, the most suitable concentrations for the drink were 15% *O. ficus-indica* pulp, 85% passion fruit pulp and 12% sucrose. The physicochemical properties (pH, °Brix, and density) of this drink remained stable for 72 h.

Prickly pear has been identified as a source of pectin and has great potential in the food industry as a gelling, thickening, and stabilizing agent [69]. Montilla et al. [70] quantified the pectins in the pulp of 3 different species of *Opuntia* from the semi-arid regions of Venezuela. The results were expressed as a percentage of an hydrogalacturonic acid (% AAG) and *O. ficus-indica* stood out with a value of $0.1531\% \pm 0.0087$. Similarly, Chaparro et al. [69] evaluated the application of pectin extracted from prickly pear in a pineapple candy. The extraction yield was 9.14%, with a degree of esterification of 62%, indicating high methoxyl content and slow gelation. This suggests that it is suitable for the food industry and the production of preserves, such as jams and sweets. Nonetheless, the yield was low compared with commercial pectin sources such as orange or apple peel. The sensory quality characteristics of the pineapple candy with prickly pear pectin achieved an acceptable level of satisfaction.

Several studies have focused on obtaining pigments from the pulp and peel of prickly pear. This fruit has an attractive color that varies from pale green, green, yellow, orange, and red to violet tones; these are due to betacyanins (red-violet) and betaxanthins (yellow-orange) [46]. Pigments can be obtained by different methods; Coba Carrera et al. [71] got a higher pigment yield lyophilizing at 60°C. The colorant obtained met all the requirements (pH 6.1, 13.71°Brix, 1.35 of nD and 7.73% total solids) according to the specified standard. In a study by Otárola et al. [72], the microencapsulation of betalains from purple prickly pears (Santiago del Estero, Argentina) was evaluated by spray drying. Encapsulation was supplemented with maltodextrin and cladode mucilage to improve stability. Pigment retention was greater than 70% at 18°C, and relative humidity was below 57%; these being the most stable conditions. The use of cladode mucilage improved encapsulation efficiency, reducing moisture content and increasing dietary fiber content. Furthermore, the authors concluded that betalains from purple prickly pears have the potential to be an encapsulating agent for atomization in the food industry.

In a study conducted by Romero et al. [61], the effect of lyophilized pulps from *Eugenia uniflora* L. and *O. ficus-indica* fruits on the oxidative stability of meat patties was evaluated. In addition, the effect of lyophilized pulps on the cooking performance, color, texture parameters, and sensory acceptance was assessed. The authors determined that the lyophilized pulps limit the oxidation of lipids stored in a refrigerator to an acceptable level for up to 15 days, with *O. ficus-indica* (red peel variety) having the greatest antioxidant activity. Moreover, this variety had the highest preference among consumers for sensory parameters. The authors highlighted the effectiveness of the studied fruits to reduce lipid oxidation in meat pies.

4. Sanky

Among endemic Andean region, edible fruits are the sanky or sancayo (*C. brevistylus*) (Figure 3) a member of the succulent plant Cactaceae family [54, 73, 74].



Figure 3. Major parts of sanky (*Corryocactus brevistylus* subsp. *puquiensis* (Rauh & Backeberg) Ostolaza) fruits. (A) Fruit, (B) mesocarp, (C) peel, (D) mucilaginous coating around sanky seeds (wet) and (E) shade-dried sanky seeds.

C. brevistylus subsp. *brevistylus* (K. Schum. ex Vaupel) Britton & Rose is a native erect, branched cactus, up to 5 m tall. Branches with 7–8 ridges, spines up to 24 cm. Flowers yellow, fruit pear like, 9 cm long, with plenty of small spines [75]. Fruit is a large berry, between 7 and 10 cm long, round, olive green, with numerous brown seeds inside [73]. Grows on rocky slopes, shrubland, from 2000 to 3500 m above sea level and is endemic southern Peru and northern Chile [73, 75].

C. brevistylus subsp. *puquiensis* (Rauh & Backeberg) Ostolaza is an endemic arboreal cactus of Peru, of basal branching, more than 5 m tall, branches 20 cm in diameter, 7–8 tuberculate ribs near the apex, spines up to 20 cm, yellow flowers, 7 cm long and edible fruit. It differs from the previous subspecies by being taller and having smaller flowers [54]. This species is distributed in the provinces of Arequipa (Huanca, Majes, Caravelí, and Caylloma), Ayacucho (Lucanas) and grows between 2500 and 3000 m above the sea level [73].

Currently, consumption and use in the food products manufactured such as drinks based on sanky pulps have increased [76]. In addition, sanky pulp processing residues can be used as an additive (stabilizer) in the food and pharmaceutical industries [77]. On the other hand, the peels, and seeds of sanky have provided interesting antioxidant and nutritional properties [78]. Sanky peel powder-derived functional ingredients showed good potential as natural llama burger-making additives as well as after their incorporation improved the sensory and chromatic properties [79].

4.1 General chemical composition

Sanky fruits from *C. brevistylus* subsp. *puquiensis* (Rauh & Backeberg) Ostolaza have a weight between 341 to 413 g and a diameter in the range of 7.7–8.4 cm (**Figure 4A** and **B**). The pulp has a pH and soluble solids (°Brix) of 2.54 and 3.99, respectively. The pulp is white flesh with small black seeds and *sui generis* flavor (**Figure 4C**). In addition, it has a gelatinous appearance and an acid taste (unpublished data). Further studies on sanky pulp are still necessary, especially in the proximal chemical composition and physicochemical properties of the different parts of the fruit (pulp, seed, and peel). **Table 17** shows the nutritional composition of the peel and seed of sanky.

The carbohydrate (~46%) and fiber (~16%) content are the main components of the sanky peels, while seeds are an important source of dietary fiber (~29%) and



Figure 4. (A) Sanky fruits of different weights, (B) diameter range of 7.7–8.4 cm, (C) cross-section in sanky fruits showing seeds and pulp, (D) sanky pulp used in jam and nectar, (E) fiber, mucilage and seeds, and (F) sanky peel used as a stabilizer.

<i>Corryocactus brevistylus</i> subsp. <i>puquiensis</i> (Rauh & Backeberg) Ostolaza			
Origin	Ayacucho (Peru)		
Crop locus	Saisa		
Altitude (m.a.s.l)	3075		
	Pulp	Peel	Seed
Moisture (g/100 g)	95.3	10.74	4.36
Protein (g/100 g)	0.2	9.19	15.56
Lipid (g/100 g)	0.1	2.68	26.10
Carbohydrate (g/100 g)	3.3	46.25	22.53
Fiber (g/100 g)	0.5	16.39	29.53
Ash (g/100 g)	0.5	14.75	2.22
Calcium (ppm)		329.56	207.81
Iron (ppm)		5.95	39.36
Zinc (ppm)		1.06	9.40
Ascorbic acid (mg/100 g)	57.1		

Taken from Muñoz et al. [78]; Nolasco and Guevara [80] and Areche et al. [81].

Table 17.
 Levels of nutrients and minerals in sanky fruit.

lipids (~26%). The dietary fiber content of the peels compared to other cacti such as prickly pear (40.8%) and dragon fruit (23.75%) is lower [82, 83]. While the contribution of the seeds is superior to the prickly pear seeds (12.47%) [84]. Dietary fibers are defined as “macromolecules present in the diet that resist digestion by endogenous enzymes in the small intestine of humans” [85]. The main effects related to dietary fiber consumption are to improve intestinal function, increase microbial biomass, blood cholesterol decrease, lower risk of cardiovascular disease, type-2 diabetes, and colorectal cancer [86, 87]. On the other hand, the fiber-rich by-products have been used to fortify various foods (as corn and wheat tortillas, bakery products, snack foods, noodles, and cooked meat products) to increase their dietary fiber content and to drive the nutraceutical industry [88–92].

The protein content of peel and seed of sanky is ~9% and ~15% (dry basis), respectively. The amino acid composition of sanky fruit proteins has not been fully characterized. The protein level of sanky peels compared to other cacti was slightly superior to that of prickly pear (6.12%) and dragon fruit (6.0%), while the seeds of these species were 4.78% and 26.3%, respectively [84, 93, 94].

The ash content in both peels and seeds was 14.75% and 2.22%, respectively. In prickly pear, seeds were found around 1.27%, while the dragon fruit seeds had a content of 6.1% (*H. polyrhizus*) and 3.1% (*H. undatus*) [84, 94]. Sanky fruit is a good source of calcium. The peels contain more calcium than the seeds, while the latter are high in iron and zinc (Table 1). The calcium content in cactus fruits was reported to be 750 ppm in jiotilla (*Escontria chiotilla*), 50 ppm in dragon fruit (*H. undatus*), 440 ppm in berry cactus (*M. geometrizans*), and 560 ppm in prickly pear (*Opuntia* sp.). While the iron content was 32.6 ppm, 7.50 ppm, 380 ppm and 12.34 ppm, respectively [95].

	Sanky	Tuna or prickly pear	Dragon fruit	
			<i>Hylocereus undatus</i>	<i>Hylocereus polyrhizus</i>
Palmitic acid (C16:0)	14.09	12.23	14.95	18.39
Palmitoleic acid (16:1 ω -7)	0.37		0.79	1.04
Stearic acid (C18:0)	2.52	0.15	6.93	8.05
Oleic acid (18:1 ω -9)	23.04	25.52	18.67	23.61
Linoleic acid (C18:2 ω -6)	56.44	61.01	55.43	45.21
α -Linolenic acid (C18:3 ω -3)	0.56	0.40–0.69	0.21	0.15
Arachidic acid (C20:0)	1.12		0.95	1.04
SFA	17.72	12.38	22.83	27.48
MUFA	23.41	25.52	19.46	24.65
PUFA	57.00	61.51	55.64	45.36

Taken from Muñoz et al. [78]; Özcan and Al Juhaime [84] and Liaotrakoon et al. [97].

Table 18.

Fatty acids composition of sanky seed oils and other Cactaceae fruits oils.

Overall, the lipid content of sanky peel is minimal (~2%). The oil content of the peels is comparable to that of orange peel (1.45%), prickly pear peel (1.55%), mango peel (2.12%), watermelon peel (2.61%), banana peel (4.51%) and dragon fruit peel (6.20%) [83, 93], while the sanky seeds are a source of lipids (~26%). Compared with prickly pear seeds (2.24–5.69%) it is superior, whereas with dragon fruit seeds (*H. undatus*) (27.5%) they are slightly similar [94, 96]. The sanky seed oil was highly unsaturated of which 23.41% are monounsaturated fatty acids (MUFA) and 57% are polyunsaturated fatty acids (PUFA) (**Table 18**). The linoleic acid (56.44%) was the major unsaturated fatty acid found in the sanky seed oil and similar to dragon fruit seed oil (*H. undatus*) [97], followed by oleic (23.04%) and palmitic (14.09%) acids. These values are comparable to prickly pear seed and dragon fruit seed oils. Palmitic, stearic and arachidic acids accounted for 14.09%, 2.52 and 1.12% of sanky seed oil, respectively. Linolenic acid (C18:3 ω -3) (0.56%) in sanky seed oil was similar to Cactaceae fruits oils [84, 97].

The proximal chemical composition of *C. brevistylus* subsp. *brevistylus* (K. Schum. ex Vaupel) Britton & Rose is currently limited. The ascorbic acid content in this subspecies (38.45 mg/100 g) was higher than that reported for another cactus fruits of 17.3 mg/100 g in jiotilla, 25.8 mg/100 g in dragon fruit, 32.5 mg/100 g in berry cactus, 14 mg/100 g in prickly pear and 17 mg/100 g in pitaya (*Stenocereus* sp.). While the “chilito” species (*Mammillaria uncinata*) has an ascorbic acid content of 1390 mg/100 g, much higher than other Cactaceae fruits, this content was very comparable with the content of ascorbic acid in the camu-camu fruit around 1451 mg/100 g [98].

4.2 Bioactive phytochemicals

There are few studies on bioactive compound profiles in sanky fruits. Phytochemical screening of the pulp and peel reported the presence of reducing sugars, lactones, triterpenes, anthocyanidins, mucilages and catechins [80].

4.2.1 Bioactive compound profile

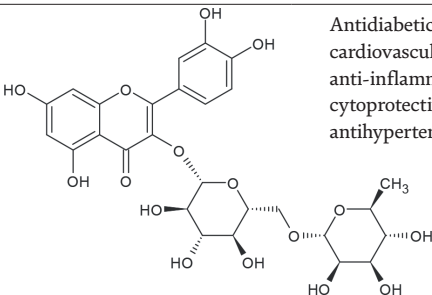
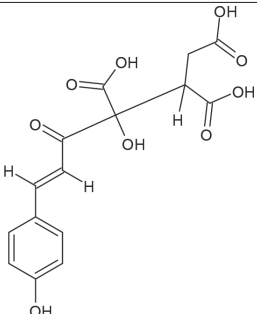
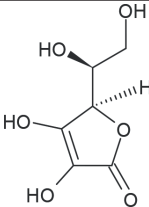
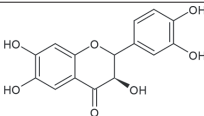
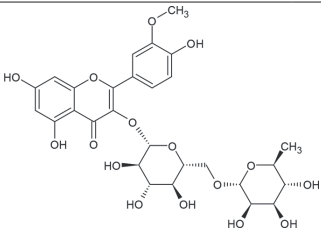
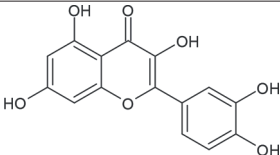
Bioactive compounds have recently been identified in lyophilized sanky pulp powder (*C. brevistylus* subsp. *brevistylus* (K. Schum. ex Vaupel) Britton & Rose) [81]. Those compounds were extracted with ethanol (three times) followed by sonication. The bioactive compounds identified were organic acids, hydroxycinnamic acids, isoamericanol derivatives, flavonoids, and sterols, and the main classes found were organic acids (12), hydroxycinnamic acids (9), and flavonoids (6). The main phytochemicals were rutin and coumaroyl isocitric acid.

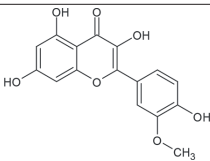
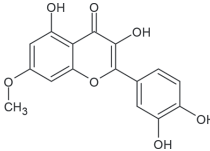
The organic acids identified were malic acid, isocitric acid, hydroxyglutaric acid, hydroxyglutaric acid isomer, homo isocitric acid, hydroxybenzoic acid, dehydroshikimic acid, ascorbic acid, benzoyl aspartic acid derivative, and azelaic acid [81]. These organic acids are widely distributed in nature and have therapeutic action. They are also used in the food industry as acidulants, preservatives, inactivating or inhibiting the growth of microorganisms and establishing a protective barrier at acid pH [99]. The hydroxycinnamic acids identified were caffeoyl-*O*-hexoside, caffeoyl isocitric acid (RT: 10.14 min; *m/z*: 353.0513), caffeoyl isocitric acid (RT: 10.42 min; *m/z*: 353.0513), coumaroyl isocitric acid (RT: 10.68 min; *m/z*: 337.0564), coumaroyl isocitric acid (RT: 11.16 min; *m/z*: 337.0563), feruloyl isocitric acid, methylcoumaroyl isocitric acid and methylferuloyl isocitric acid [81]. These compounds are of interest because of their biological properties that include antioxidant activity, anticancer activity, improves blood pressure and metabolic syndrome [100, 101]. The flavonoids identified were rutin, isorhamnetin-*O*-rutinose, taxifolin, quercetin, isorhamnetin and rhamnetin (**Table 19**). The reports highlighted that bioactive molecules of sanky exerts strong antioxidant-antiradical activity, gastroprotective effects and other bioactivities. Flavonoids are the most studied bioactive compounds [115] and are widely distributed in different parts of Cactaceae fruits (pulp, peel, seeds, and cladodes) [95, 116]. In addition, they provide a high antioxidant potential [117]. The quantification of the detailed phytochemical compounds of the different parts of the sanky fruit (pulp, seed, and peel) is still necessary.

4.2.2 Polyphenols and antioxidant activity

The total phenolic contents (TPC) of peels from sanky (*C. brevistylus* subsp. *puquiensis* (Rauh & Backeberg) Ostolaza) ranged from 14.2 to 43.9 mg gallic acid equivalent (GAE)/g dry weight [118], while the TPC of lyophilized sanky pulp powder from sanky (*C. brevistylus* subsp. *brevistylus* (K. Schum. ex Vaupel) Britton & Rose) was 24.24 mg GAE/g dry weight, and total flavonoid content (TFC) was 13.33 mg quercetin equivalents/g dry weight [81]. When compared to sanky pulp, white and red pitayas showed lower TPC (3.52–4.91 mg GAE/g) [119, 120]. While in different varieties of cactus pear fruit pulp the TPC varied between 1.68 and 22.08 mg GAE/kg [119].

The phenolic compounds are known for their antioxidant capacity [117]. Antioxidant activity measured in lyophilized sanky pulp powder extract by DPPH, ABTS and FRAP assays presented the following values: $IC_{50} = 47.45 \mu\text{g/mL}$, $IC_{50} = 225.12 \mu\text{g/mL}$, and $155.34 \mu\text{mol Trolox/g dry weight}$, respectively. Antioxidant activity is probably due to the presence of the following phytochemicals: organic acids (ascorbic acid), hydroxycinnamic acids, isoamericanol derivatives, and flavonoids (rutin, taxifolin, quercetin, isorhamnetin and rhamnetin), these compounds found in food matrices have shown high antioxidant activity [12].

Bioactive compounds	Structures	Functional effects
Rutin MW = 610.517 g/mol MF=C₂₇H₃₀O₁₆		Antidiabetic, antioxidant, cardiovascular, anticancer, anti-inflammatory, antiviral, cytoprotective, hypolipidemic, and antihypertensive effects
Coumaroyl isocitric acid MW = 338.266 g/mol MF=C₁₅H₁₄O₉		
Ascorbic acid MW = 176.124 g/mol MF=C₆H₈O₆		Considered one of the most effective natural antioxidants, promising anti-cancer agent
Taxifolin MW = 304.251 g/mol MF=C₁₅H₁₂O₇		Inhibits the proliferation, migration, and invasion of breast cancer cells
Isorhamnetin-O-rutinose MW = 624.544 g/mol MF=C₂₈H₃₂O₁₆		Insulin sensitizer, and hepatoprotective effect
Quercetin MW = 302.235 g/mol MF=C₁₅H₁₀O₇		Antioxidant, anti-inflammatory, anticancer, cardioprotective, and neuroprotective effects

Bioactive compounds	Structures	Functional effects
Isorhamnetin MW = 316.262 g/mol MF=C16H12O7		Regulation of apoptosis and anti-osteoporosis, anti-inflammatory, cerebrovascular protection, and antioxidant effects
Rhamnetin MW = 316.262 g/mol MF=C16H12O7		Suppresses the growth of human breast cancer cells

Taken from Ghorbani [102]; Patel and Patel [103]; Caparica et al. [104]; Sun, et al. [105]; Barba et al. [106]; Shenoy et al. [107]; Van Gorkom et al. [108]; Jia et al. [109]; Geurenova et al. [110]; Li et al. [111]; Ay et al. [112]; Gong et al. [113]; and Lan et al. [114].

Table 19.
 Some bioactive compounds in lyophilized sanky pulp powder.

4.3 Commercial applications of sanky fruits

Due to their technological characteristics, sanky fruits can be well used for industrial processes. Currently, within the cosmetic derivatives creams, shampoos, and soaps have been developed. For food applications, sanky jam (pulp and seed) (**Figure 4D** and **E**), sanky nectar (pulp) and sanky peel (**Figure 4F**) extract a stabilizer in meat products during refrigerated storage have been developed [121]. The demand for sanky by consumers in the domestic market continues to grow, especially in the form of pulp and fresh fruit.

The production of jams from sanky fruits is being developed recently. Some studies are focused on evaluating the sensory and physicochemical properties as well as the influence of the addition of pectin and carboxymethyl cellulose. The conditions of acceptability of the sanky jam presented a concentration of soluble solids (67.92°Bx); acidity (2.50%, expressed as citric acid); pH 3.17; and viscosity of 8878.40 cP [122]. In another study, the nutritional and sensory properties of a sanky jam sweetened with fructooligosaccharides (FOS) were evaluated. The final product reached a pH of 3.7, soluble solids of 66°Brix, titratable acidity of 3.41%, the crude fiber of 0.3%, ascorbic acid of 44 mg/100 g, total polyphenols of 381 mg GAE/100 g, and an antioxidant capacity of 65.92 mg Trolox/100 g [123]. Some unpublished data refers to the elaboration of sanky compote sweetened with panela and bee honey and others to the formulation of fruit mix compote (sanky, banana, and mango). Featherstone [124] mentions that jams are products of a combination of fruits (or fruit pulp, puree, juice, or concentrates) and sugar followed by heat treatment of them to produce a tasty product of sufficiently high sugar (>65%) content. Fruit jams are a source of energy and carbohydrate [125]. In addition to their nutritional composition, fruit jams are a source of bioactive components that have shown antioxidant activity. Fruit jams (such as blueberry, blackberry, blackcurrant, cranberry, and raspberry) have shown

a polyphenol content between 170.32 and 473.91 mg GAE/100 g, the total flavonoids ranged between 2.61 and 11.43 mg quercetin equivalents (QE)/100 g and the antioxidant activity by ABTS assay as ranging from 6.10 to 36.56 μ M Trolox/g [126].

Other sanky-based products are nectar and functional beverages. Neves et al. [127] define nectar as a category of packaged beverage that presents a juice content ranging from 25 to 99%. In addition, nectar can contain sweeteners, coloring, and preservatives. As part of the use of sanky fruits, **Figure 5** shows the block diagram of sanky nectar processing. The sanky fruit presents the following yields for the whole fruit. The pulp represents around ~57% (fresh weight), this fraction contains mucilage that could be used as a thickener in the preparation of various food products such as:

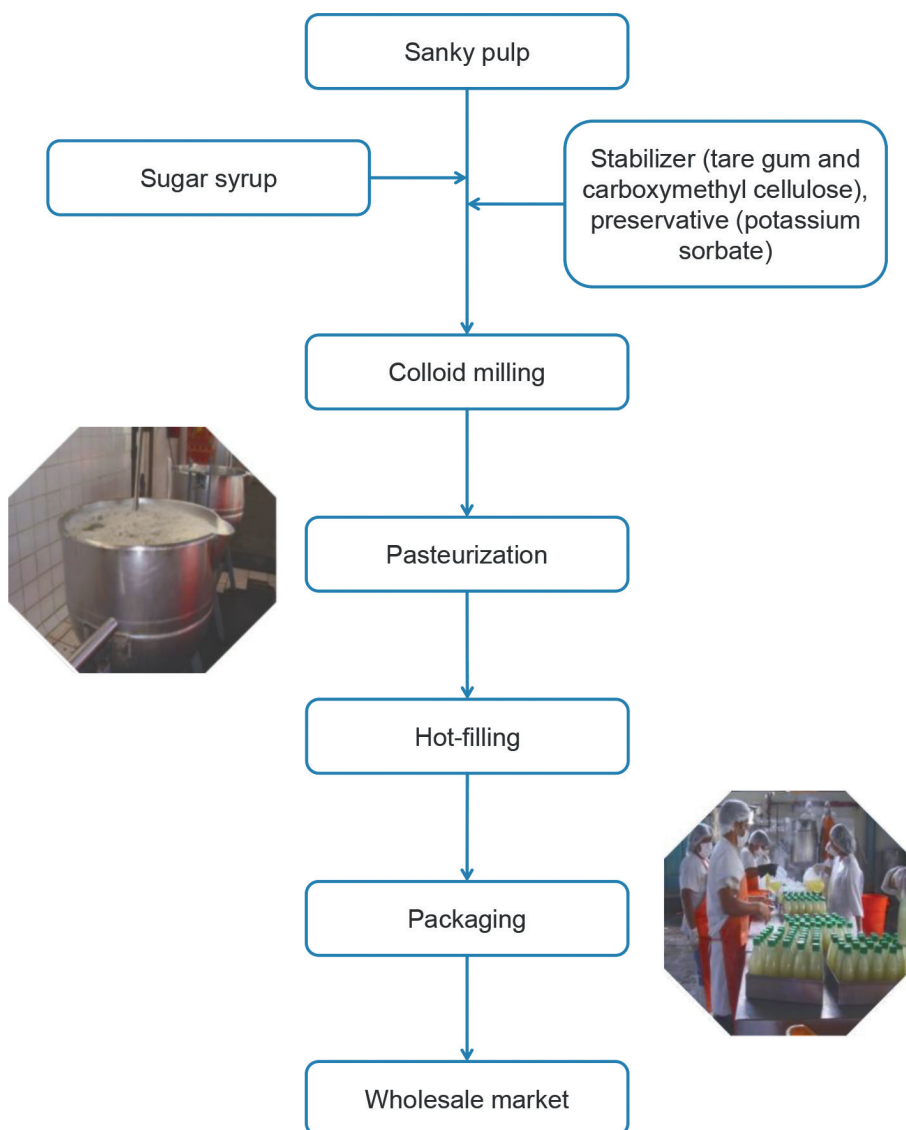


Figure 5. Block diagram for obtaining sanky nectar (source: “Aprovechamiento industrial en los bosques naturales de sanky,” n.d.).

baby food, compotes, pasta, etc. [77]. Mucilages can also be used as pharmaceutical excipients and wall materials for vegetable oils, essential oils, emulsions, etc. [128, 129]. The peels represent around ~35% (fresh weight). The peels are an important source of dietary fiber, in addition, they contain antioxidant phenolic compounds [14, 130]. While the seeds represent ~7%. Fruit seeds have a high oil content, are rich in monounsaturated and polyunsaturated fatty acids. They also contain other phytochemicals among them phytosterols, phospholipids, glycolipids, tocopherols, tocotrienols, carotenoids and polyphenols [131].

Sanky fruits are generally harvested using a long-handled fruit picker, followed by collection in crates. After harvesting, the sanky fruits are selected and classified (the fruits are selected manually, removing those that show signs of deterioration and/or breakage). Washing is carried out with water by immersion to remove foreign substances and particles, while disinfecting is done with sodium hypochlorite solution at 100 ppm. Peeling is carried out by cutting the fruits in half with stainless steel knives, allowing the separation of pulp and peel. The sanky pulp is pasteurized at atmospheric pressure until boiling temperature for 1 second. Then, the pasteurized pulp is packed in 1 kg high-density polyethylene bags and then stored at a temperature of 5°C. Sanky pulp is used for the processing of mixed fruit drinks (noni, sanky and graviola) (<http://vidanatural.pe/>), according to the product information, this beverage stimulates the immune system, has antioxidant activity and reduces the levels of osteoporosis due to its calcium content. Fruit juices, beverages and nectars have shown antioxidant activity due to their high-value nutrient and bioactive components [132, 133].

Sanky fruit peels have been used to improve the chromatic and sensory characteristics of llama meat (*Lama glama*) during refrigerated storage, however, it did not inhibit microbial growth [121]. The effect of the incorporation of fruit peel powder on the quality and shelf-life characteristics of meat and derived products has been demonstrated. In addition, many extracts have shown an inhibitory effect on the growth of Gram-positive and negative strains [134, 135]. Bioactive compounds as polyphenols present in fruit peels provide an antioxidant effect and inhibit lipid oxidation. In many cases, the natural antioxidants present in these matrices provide better protection compared to synthetic antioxidants [135, 136].

5. Conclusions and future research

Edible cacti (Cactaceae) from the South American Andes contain a range of nutrients including macro- and micronutrients and bioactive compounds. The bioactive components present in pitahaya, tuna or prickly pear, been shown a wide range of biological activities. Even though there is abundant information about pitahaya and prickly pear, these fruits have been used as natural colorants, due to the presence of betalains, anthocyanins, carotenoids, and chlorophylls. In addition to having several pharmacological properties and great potential as functional foods.

The sanky belongs to the Cactaceae family. This fruit is currently being marketed as fresh fruit, pulp, and processed products. Sanky seeds are a source of proteins, lipids, fiber, and iron. Sanky peels are a source of proteins, lipids, fiber, and iron. While sanky peels are a source of carbohydrates and calcium and the pulp is rich in ascorbic acid. Sanky fruit contains several beneficial bioactive compounds in its parts (pulp, seed, and peel), including organic acids, hydroxycinnamic acids, isoamericanol derivatives, flavonoids, sterols, and fatty acids. Sanky extracts showed a biological activity as including antioxidant and gastroprotective. These effects could be due to the components such

as hydroxycinnamic acids, flavonoids, and ascorbic acid or other bioactive compounds present in the fruit. The most abundant bioactive compounds in lyophilized sanky pulp powder are coumaroyl isocitric acid (hydroxycinnamic acid) and rutin (flavonoid). Some processed products based on sanky pulp are nectar and jam. Stabilizers for application in the food industry are obtained from by-products such as peels.

There are research opportunities for sanky fruit focused on human consumption and applications in the food industry. The chemical composition focused on the characterization of the macro- and micronutrients and bioactive compounds of the by-products (pulp, seed, and peel) of both species should be studied. Polysaccharide and sugar water-soluble characterization and evaluate the antioxidant activity *in vitro* in the mucilage remains to be studied. The impact of sanky fruit mucilage on human gut microbiota remains to be studied. Evaluate the sanky fruit mucilage as a new wall material for microencapsulation by spray drying of Sacha inchi oil.

Conflict of interest

The authors declare no conflict of interest.

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