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## RED PITAHAYA HYLOCEREUS UNDATUS (HAWORTH) BRITTON & ROSE GROWN ON THE PERUVIAN COAST: PHYSICOCHEMICAL, NUTRITIONAL, AND BIOACTIVE CHARACTERISTICS

秘鲁海岸生长的红色火龙果火龙果（海沃思）布里顿和玫瑰：物理化学、营养和生物活性特性

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### Abstract

Pitahaya (*Hylocereus* spp.) is a cactus native to the Americas. It is *Hylocereus undatus*, the most commercial variety, so data on its nutritional composition are required. The aim of this investigation was to examine the physicochemical, nutritional, and bioactive characteristics of the red Pitahaya *Hylocereus undatus* (Haworth) Britton & Rose grown on the Peruvian coast. Analysis of physicochemical characteristics, nutritional composition, bioactive compounds, and antioxidant capacity was performed using standardized methods. From the proximal composition, the fiber content ( $4.30 \pm 0.02$  g/100 g) and total carbohydrate content ( $15.01 \pm 0.16$  g/100 g) were outstanding. Likewise, among the bioactive compounds, the red Pitahaya displayed acceptable levels of vitamin C ( $7.80 \pm 0.01$  mg/100 g) and total betalains ( $5.93 \pm 0.01$ -mg betacyanin equivalent/100 g), highlighting the levels of total polyphenols ( $101.43 \pm 1.79$  mg of acid gallic equivalent/100 g) and antioxidant capacity ( $1215 \pm 2.22$ - $\mu$ mol trolox equivalent/100 g) evaluated by the DPPH assay. The results confirmed that the red Pitahaya *Hylocereus undatus* (Haworth) Britton & Rose grown on the Peruvian coast is a promising source of nutritional and bioactive compounds to be used as a functional ingredient in the food industry.

**Keywords:** vitamin C, *Hylocereus*, antioxidant activity, bioactive compounds, betalains



**摘要** 火龙果(火龙果属)是一种原产于美洲的仙人掌。它是最具商业价值的品种, 因此需要其营养成分数据。本研究旨在研究秘鲁海岸生长的红色火龙果(哈沃思)布里顿与罗斯的物理化学、营养和生物活性特性。使用标准化方法分析了物理化学特性、营养成分、生物活性化合物和抗氧化能力。从近端组成来看, 纤维含量( $4.30 \pm 0.02$  克/100 克)和总碳水化合物含量( $15.01 \pm 0.16$  克/100 克)非常突出。同样, 在生物活性化合物中, 红色火龙果的维生素 C ( $7.80 \pm 0.01$  毫克/100 克) 和总甜菜红素 ( $5.93 \pm 0.01$  毫克甜菜红素当量/100 克) 含量也达到了可接受水平, 突出了通过 DPPH 测定评估的总多酚含量 ( $101.43 \pm 1.79$  毫克没食子酸当量/100 克) 和抗氧化能力 ( $1215 \pm 2.22$   $\mu\text{mol}$  水杨酸当量/100 克)。结果证实, 生长在秘鲁海岸的红色火龙果火龙果(哈沃思)布里顿与罗斯是一种有前途的营养和生物活性化合物来源, 可用作食品工业中的功能性成分。

**关键词:** 维生素 C、火龙果、抗氧化活性、生物活性化合物、甜菜碱

## I. INTRODUCTION

The dragon fruit, known as pitahaya or pitaya, belongs to the cactaceae family, with the most commercial varieties being those belonging to the genus *Hylocereus*, which has around 18 species [1, 2]. It is a non-climacteric fruit native to Central and South America and is currently cultivated in many countries around the world [3, 4]. *Hylocereus undatus* (Haw.) Britton & Rose is the most economically important species worldwide because of its cultivation volume and export levels [5]. The *H. undatus* species has reddish skin and red or white flesh varieties [6]. Currently, there is great interest in this fruit, mainly for its nutritional and organoleptic properties and physical form, which is called the dragon fruit [7]. This fruit can be consumed fresh or processed, in the form of beverages, cosmetics, pharmaceuticals, or used in the development of functional ingredients because it is a food rich in phenolic compounds, flavonoids, vitamins, fiber, and minerals [3, 4, 8–13]. Several studies have evaluated the functional characteristics of different varieties of pitahaya, both red and white, with the red varieties showing a higher content of phenolic compounds and antioxidant capacity, mainly because the red varieties have a higher content of betalains [14–17]. Betalains are soluble nitrogen-containing pigments found in many species of the Caryophyllales order, including the Cactaceae family. They have biological properties that help prevent degenerative diseases such as cancer, cardiovascular and gastrointestinal diseases, diabetes, and obesity. They are used in the cosmetic and food industries because they are natural dyes with antioxidant properties that can be used to improve human health [18–21]. The cultivation of Pitahaya presents a viable alternative for regions characterized by limited water resources, such as the Peruvian coast with its arid climate and low rainfall. This species

demonstrates resilience to various adverse climatic conditions, and its cultivation requirements are minimal [12, 22]. Concerning *Hylocereus undatus* (Haworth) Britton & Rose, which is cultivated on the Peruvian coast, there is a paucity of information regarding its nutritional and bioactive properties and antioxidant capacity. This knowledge is essential for the development of food and pharmaceutical ingredients. In this context, this research aims to study the nutritional and bioactive characteristics of the red Pitahaya *Hylocereus undatus* (Haworth) Britton & Rose grown on the Peruvian coast and elucidate its use as a functional ingredient or for human consumption.

### A. Scientific Novelty of the Research

The studied red Pitahaya variety *Hylocereus undatus* from the Peruvian coast is a promising source of nutritional and bioactive compounds for the food industry and for the benefit of human health. Therefore, this research establishes a database for future research on the cultivation, processing, and application of the red Pitahaya. Likewise, analysis of the nutritional and bioactive composition of red pitahaya in a specific region (Peruvian coast) using standardized methods will allow identification of red Pitahaya from the Peruvian coast as a functional ingredient with beneficial potential for human health.

### B. Theoretical Contribution

This fruit exhibits significant potential for development in our country as it has garnered considerable acceptance due to its flavor and morphology, which elicits substantial interest; besides, it has nutritional and bioactive properties that are beneficial to health. Likewise, the potential applications and technological utilization of cacti are extensive and encompass numerous domains. The disciplines of science and technology in the domains of food and

medicine are highly interconnected.

In recent decades, numerous scientific studies have shown that cacti are rich sources of phytochemicals with great potential for functional and medicinal applications. However, there are many and diverse factors that affect the composition of vitamins, pigments, and other bioactive substances in cacti. For this reason, a survey of the variation in the contents and nature of these constituents is valuable. On the other hand, some components of cactus plants can be altered by processing for preservation or drying, although they can also be modified to improve their properties.

### C. Practical Contribution

The contributions of this research encompass multiple dimensions:

- From a societal perspective, it aims to investigate novel sources of foods with functional properties. This is particularly relevant given that the contemporary global population is significantly affected by chronic degenerative diseases, including cancer, cardiovascular disorders, and diabetes, among others. Concurrently, various strategies have been developed to address or prevent these health issues. A potential approach to mitigate these diseases involves the incorporation of antioxidant-rich foods into daily dietary patterns. These foods, such as those derived from the red Pitahaya, contain high levels of antioxidants including flavonoids, carotenoids, and tannins.

- From an economic standpoint, this research seeks to promote the cultivation and consumption of a fruit that currently holds significant value in international markets and may serve as a viable option for the agro-export industries of various nations.

## II. MATERIALS AND METHODS

### A. Plant Materials

The red Pitahaya fruits were obtained from an orchard nursery situated in Lot 40 C, La Virgen sector, La Esperanza population center, Huaral province, Lima department, Peru. The geographical coordinates of this location are Latitude -11.442 and Longitude -77.147, positioned in the central coastal region of Peru, at an elevation of 246.4 m.a.s.l. The site is characterized by an average annual temperature of 18.3°C, average annual rainfall of 10 mm, and 83.8% average relative humidity per annum. The fruits were harvested at their commercial maturity stage, during the second fruiting cycle of the plants, free from pests and physical

damage.

### B. Sampling and Sample Preparation

The fruits were selected randomly from plants exhibiting optimal phenotypic characteristics, from which five lots of approximately 10–15 kg were obtained through random sampling. For physicochemical and bioactive compound analyses, the calyx was removed from the fruits, which were then washed, disinfected, and subjected to freeze-drying and grinding. The dehydrated samples were stored under refrigeration for subsequent analyses. Results are presented as the mean of each lot (n=5).

### C. Taxonomic Study

The plants and fruits were identified through a taxonomic and botanical study by specialists from the Natural History Museum of the Universidad Nacional Mayor de San Marcos, Lima, Peru.

## III. PHYSICAL-CHEMICAL COMPOSITION

### A. Physical Analysis

For the measurement of the physical analysis, 10 fruits were selected, and the average dimensions (longitudinal and transverse diameters) were measured using a KAMASA KM447 calibrator. The average weight and yields in the pulp and peel of the fruits were also measured [23].

### B. Proximal Analysis

The proximate analysis was performed using the AOAC methodology [24]. The water content was determined by drying the sample in an oven at 105°C for 5 h. Similarly, the protein content was determined using the Kjeldhal method, with a conversion factor of 6.25. Acid hydrolysis was used to determine fiber content. Fat content was determined using the Soxhlet method with petroleum ether as the solvent. Ash content was determined by ashing the samples at 550°C ± 15°C. Finally, the carbohydrate content was determined by subtracting 100 from the water, protein, fat, and ash contents [23]. For the determination of total energy, 4, 9, and 4 kcal/g were used for proteins, fats, and carbohydrates, respectively.

### C. Physicochemical Analysis

The soluble solids were determined using a manual refractometer ATC (0-30 °Brix) with the fruit pulp used. The total acidity was also determined using a potentiometer (Ezodo PL-

700PV) with 0.1-N NaOH solution; the result was expressed as a percentage of citric acid. The maturity index was determined from the soluble solids and total acidity by dividing the soluble solids by the total acidity [23].

#### IV. BIOACTIVE COMPONENTS AND ANTIOXIDANT CAPACITY

##### A. Vitamin C Content

The content of vitamin C (ascorbic acid) was determined using the modified 2,6-dichlorophenol indophenol titration method with oxalic acid instead of metaphosphoric acid for extraction. The results were expressed as mg ascorbic acid per 100-g sample [25].

##### B. Betalain Content

The betalain content was determined using the spectrophotometric method described by Castellanos-Santiago and Yahia [26]. Extraction was performed by sonication (bath sonicator Branson 2510®, Danbury, USA) of 100 mg of dry sample with water for 15 min in the dark. Subsequently, it was centrifuged in a Hettich Zentrifugen® Mod. Universal 32 (Germany) at 12000 RPM, and the supernatant was separated. The supernatant was directly read at 538 nm using a Thermo Scientific Genesys 10S UV spectrophotometer. For the calculation of the total betalaine content, the following expression was used: (mg betacyanin equivalent (BTCE)/100 g) =  $\{(A \times FD \times PM \times V \times 1000) / (\epsilon \times L \times W)\} \times 100$ , where A is the absorbance at 538 nm, FD is the dilution factor, PM is the molecular weight (betanin = 550 g/mol), V is the volume of the extract,  $\epsilon$  is the molar extinction coefficient (betanin = 60000 L/mol.cm), L is the cell length (1 cm), and W is the weight of the sample (g).

##### C. Polyphenol Extraction

Bioactive extracts were obtained following the recommendations of Jiménez-Escrig et al. [27], with some modifications. 0.5 g of dry sample was dissolved in 20 mL of a methanol/water solution and acidified with 2-N HCL (50:50% v/v, pH 2) for 1 h at room temperature. Subsequently, it was centrifuged for 15 min at 3500 rpm, and the supernatant was collected. The remaining residue was treated with 20 mL of an acetone-water mixture (70:30 v/v) for 1 h and subsequently centrifuged according to the parameters described above.

##### D. Total Polyphenol Content

Total polyphenol content was determined

according to the Folin-Ciocalteu methodology described by Singleton and Rossi [28], with some modifications. The results are expressed as mg gallic acid equivalent (GAE) per 100 g of sample. Spectrophotometric measurements were performed at 765 nm using a Thermo Scientific Genesys 10S UV spectrophotometer.

##### E. Antioxidant Capacity Analysis

The DPPH assay was performed according to the methodology described by Brand-Williams et al. [29] with some modifications. A standard solution was prepared by dissolving 0.02 g of trolox in 100 mL of 80% methanol, from which different dilutions were made to obtain a standard curve. Trolox concentrations ranged from 100 to 800  $\mu$ M. The reagent DPPH (2,2-diphenyl-1-picrylhydrazyl) was used to act as a reducing agent for the antioxidants to be evaluated by measuring the absorbance at 515 nm in a Thermo Scientific Genesys 10S UV spectrophotometer. The results are expressed as  $\mu$ mol trolox equivalent (TE) per 100 g of sample.

##### F. Statistical Analysis

The results of each analysis are expressed as the mean  $\pm$  standard deviation (SD) of five replicates, with the exception of fruit physical characteristics (10 replicates).

#### V. RESULTS AND DISCUSSION

The red Pitahaya examined in this study belonged to the Cactaceae family, specifically the species *Hylocereus undatus* (Haworth) Britton & Rose, as indicated in Table 1.

Table 1. Taxonomic and botanical study of the red Pitahaya (*Hylocereus undatus*) (The authors' elaboration)

<b>Kingdom</b>	Plantae
<b>Sub-region</b>	Tracheobionta
<b>Division</b>	Magnoliophyta
<b>Class</b>	Magnoliopsida
<b>Sub-class</b>	Caryophyllidae
<b>Order</b>	Caryophyllales
<b>Family</b>	Cactaceae
<b>Subfamily</b>	Cactoideae
<b>Genre</b>	<i>Hylocereus</i> (Berger) Britt & Rose
<b>Species</b>	<i>Hylocereus undatus</i> (Haworth) Britton & Rose
<b>Tribe</b>	<i>Hylocereeae</i>
<b>Common name</b>	Red Pitahaya

The genus *Hylocereus* (A. Berger) Britton & Rose contains approximately 18 tropical American species with climbing plants with aerial roots or of epiphytic nature [6]. The average weight of the red Pitahaya was  $307.8 \pm$

113.0 g; likewise, the average dimensions were  $91.4 \pm 13.5$  mm longitudinally and  $73.2 \pm 14.5$  mm transversely (Table 2). These values were higher than those described by Goenaga et al. [7] (211.7 g, 47.6 and 55.4 mm, respectively) for the same fruit cultivar from Puerto Rico.

Table 2.  
Average weight and dimensions of red Pitahaya (*Hylocereus undatus*) (The authors' elaboration)

Weight (g)	Longitudinal section (mm)	Cross-section (mm)
$307.8 \pm 113.0$	$91.4 \pm 13.5$	$73.2 \pm 14.5$

Mean value  $\pm$  SD of fresh weight; n=5

However, Hernández-Ramos et al. [5] reported fruits of *Hylocereus undatus* from Mexico, which were larger than those reported in the present investigation: 122.8 mm in length and 86 mm in transverse diameter; they also had an average weight of 466.94 g.

Weight and dimensions depend on the moment when the fruits are harvested because they exhibit sigmoidal behavior and a strong decrease after the appearance of color that is reported 24-25 days after floral anthesis [30].

Fruit size and weight vary with variety or cultivar, use of good agricultural practices, soil type, and environmental conditions, among others [31]. On the other hand, several authors concluded that the most relevant characteristics of Pitahaya fruit are total weight, pulp weight, length, diameter, pericarp thickness, total soluble solids, number, length, and width of bracts [22].

Regarding the proximate analysis of the fruit, Table 3 presents the results expressed on a wet and dry basis. The Pitahaya fruit exhibits a high moisture content, exceeding 80%, with the pulp demonstrating the highest moisture content. The moisture values ( $84.15 \pm 0.15\%$ ) were slightly lower than those reported by Nur et al. [11] ( $86.33 \pm 0.68\%$ ) and Islam et al. [32] ( $87.90 \pm 0.003\%$ ) for *Hylocereus undatus* from Bangladesh.

Table 3.  
Proximate analysis of red Pitahaya (*Hylocereus undatus*) (The authors' elaboration)

	Wet basis (g/100-g fresh weight)	Dry base (g/100-g dry sample)
Total solids	$15.85 \pm 0.55$	
Humidity	$84.15 \pm 0.15$	
Total protein	$0.12 \pm 0.02$	$0.64 \pm 0.02$
Fat	$0.15 \pm 0.03$	$0.80 \pm 0.28$
Ash	$0.57 \pm 0.02$	$3.02 \pm 0.30$
Crude fiber	$4.30 \pm 0.02$	$22.83 \pm 4.72$
Carbohydrates	$15.01 \pm 0.16$	$79.69 \pm 6.67$
Total energy (kcal/100 g)	$61.85 \pm 0.40$	$328.37 \pm 0.40$

Mean value  $\pm$  SD of fresh weight; n = 5; \* protein factor = 6.25

Protein, fat, and ash contents were relatively low; the values are in agreement with those obtained by Obregón-La Rosa et al. [12] for red Pitahaya fruits from the Peruvian coast. Likewise, these results are in agreement with those by Hernández-Ramos et al. [5] and Mercado-Silva [33] for fruits from Mexico.

From the results of the proximal composition, the fiber content of red Pitahaya ( $4.30 \pm 0.02$  g/100 of fresh weight) stands out, very similar to that reported by Obregón-La Rosa et al. [12] ( $4.30 \pm 0.75$ ) and Nur et al. [11] ( $4.06 \pm 0.79$  g/100-g fresh weight) for *Hylocereus undatus* fruits from Peru and Bangladesh, respectively.

Several studies have demonstrated the health effect of dietary fiber consumption, mainly on gastrointestinal and colon diseases, as well as its preventive effect on cardiovascular diseases, cancer, obesity, and diabetes [34–36].

Table 3 shows that *Hylocereus undatus* red Pitahaya exhibited significant energy ( $61.85 \pm 0.40$  kcal/100 g) and total carbohydrate ( $15.01 \pm 0.16$  g/100 g) contents. Nur et al. [11] found energy ( $25.74 \pm 1.34$  kcal/100 g) and total carbohydrate ( $4.99 \pm 0.71$  g/100 g) values lower than those reported in the present study. Differences in carbohydrate and total energy contents could be due to variations in soil type, climatic characteristics and conditions, and genetic variations [37, 38].

The total acidity, pH, and soluble solid results agree with those reported by Obregón-La Rosa et al. [12] for red Pitahaya fruits, in this case, *H. undatus* from the Peruvian coast (Table 4). Lima et al. [39] reported total acidity values ranging from 0.09 to 0.17 g citric acid/100 g for *Selenicereus megalanthus*, *Selenicereus setaceus*, *Hylocereus undatus*, and *Hylocereus costaricensis* in Pitahaya fruits from Brazil, which were lower than those observed in the present study.

Table 4.  
Physical-chemical analysis of red Pitahaya (*Hylocereus undatus*) (The authors' elaboration)

Component	Content
Total acidity (g citric acid/100 g) (TTA)	$0.26 \pm 0.01$
pH	$4.16 \pm 0.02$
Soluble solids (°Brix) (SST)	$13.83 \pm 0.58$
Maturity index (SST/TTA)	$53.53 \pm 1.18$

Mean value  $\pm$  SD of fresh weight; n = 5

Soluble solids, which are related to sweetness, represent an important quality parameter in

pitahaya. The values reported in the present study ( $13.83 \pm 0.58$  °Brix) were higher than those reported for the same species by Nur et al. [11] ( $9.23 \pm 0.13$  °Brix), Arivalagan et al. [9] ( $9.15 \pm 0.35 - 10.9 \pm 0.1$  °Brix), Islam et al. [32] ( $11 \pm 0.03$  °Brix), and Alam et al. [8] ( $0.50 \pm 0.00 - 10.20 \pm 0.10$  °Brix). However, their values were lower than those reported by Hernández-Ramos et al. [5] ( $14.41 \pm 0.26$  °Brix).

With respect to the maturity index value, which represents the relationship between soluble solids and total acidity, the value found ( $53.53 \pm 1.18$ ) was higher than that reported by Hernández-Ramos et al. [5] ( $51.92 \pm 3.09$ ) for *Hylocereus undatus* from Mexico due to provenance, cultivation, and climatic conditions.

The vitamin C value found for the variety *Hylocereus undatus* ( $7.80 \pm 0.01$  mg/100 g) was lower than those reported by Hernandez-Ramos et al. [5], Islam et al. [32], Nur et al. [11], Alam et al. [8], and Mercado-Silva [33] ( $8.94 \pm 0.84$ ,  $8.50 \pm 0.23$ ,  $9.90 \pm 0.04$ ,  $9.99 \pm 0.03 - 14.81 \pm 0.00$ , and  $25.00$ -mg ascorbic acid/100 g, respectively) (Table 5). However, the values for vitamin C were higher than those of other fruits native to the Andean region, such as cherimoya ( $3.3$  mg/100 g), cocona ( $4.4$  mg/100 g), pomegranate ( $5.2$  mg/100 g), fig ( $2.9$  mg/100 g), lucuma ( $2.2$  mg/100 g), and loquat ( $1.2$  mg/100 g) [40].

Table 5.

Analysis of bioactive compounds and antioxidant capacity of red Pitahaya (*Hylocereus undatus*) (The authors' elaboration)

Bioactive Compound	Content
Vitamin C (mg/100-g fresh weight)	$7.80 \pm 0.01$
Total polyphenol content (mg GAE/100 g)	$101.43 \pm 1.79$
Total betalains (mg BTCE/100-g fresh weight)	$5.93 \pm 0.01$
DPPH ( $\mu$ mol TE/100-g fresh weight)	$1215 \pm 2.22$

Mean value  $\pm$  SD of fresh weight; n = 5

The content of total polyphenols ( $101.43 \pm 1.79$ -mg GAE/100 g) was lower than those reported by Alam et al. [8] ( $148.92 - 163.13$ -mg GAE/100 g) and Mahattanatawee et al. [41] ( $107.58$ -mg GAE/100 g) from Bangladesh and the United States, respectively. However, these values were higher than those reported by Moo-Huchin et al. [36] ( $58.89$  mg-GAE/100 g), Sim Choo and Khing Yong [42] ( $28.65$ -mg GAE/100 g), and Xavier et al. [16] ( $28.66$ -mg GAE/100 g) for red Pitahaya fruits from Mexico, Malaysia, and India, respectively.

Paško et al. [13] identified the phenolic compounds in three types of Pitahaya: *H. costaricensis*, *H. undatus*, and *H. megalanthus*, three types of phenolic acids (caffeic, gallic, and

protocatechuic), and three types of flavonoids (myricetin, rutoside, and quercetin) as polyphenols.

The total polyphenol content observed in the present study was higher than that reported for orange ( $75 \pm 10$ -mg GAE/100 g) and banana ( $51 \pm 7$ -mg GAE/100 g) but lower than that of guava ( $138 \pm 31$ -mg GAE/100 g) and carambola ( $131 \pm 54$ -mg GAE/100 g) [42, 43] (Table 5).

Betalains are water-soluble nitrogenous pigments divided into betacyanins and betaxanthins. Betalamic acid is the main constituent of all betalains. Red and violet hues result from different substitution patterns in betacyanins, whereas different amino acid or amine side chains determine the color of betaxanthins [18, 21, 44]. García-Cruz et al. [45] reported that the color of Pitahaya pulp, characterized by a purple-reddish coloration with yellow shades, is attributable to the presence of betacyanins and betaxanthins, respectively.

The results for betalains ( $5.93 \pm 0.01$ -mg BTCE/100-g fresh weight) were lower than those reported by Singh et al. [46] ( $8.78 - 17.08$ -mg BTCE/100 g) and Arivalagan et al. [9] ( $14.4 - 23.0$ -mg BTCE/100 g) for *Hylocereus undatus* fruits from India. However, these values were higher than those reported by Hernández-Ramos et al. [5] ( $0.02$ -mg BTCE/100 g) for the fruits of *H. undatus* from Mexico.

The antioxidant capacity of foods is determined by a combination of diverse antioxidants with varying mechanisms of action. Multiple methods exist for this determination, with DPPH being one of the most widely utilized. This method is commonly employed for aqueous organic extracts containing hydrophilic and lipophilic components [43, 47–49].

The DPPH value reported in the present study ( $1215 \pm 2.22$ - $\mu$ mol TE/100 g) was much higher than those reported by Moo-Huchin et al. [36] ( $198.97 \pm 14.12$ - $\mu$ mol TE/100 g) and Arivalagan et al. [9] ( $108 - 276$ - $\mu$ mol TE/100 g). The values reported in the investigation are comparable to those reported by Pellegrini et al. [50] for the following foods: cabbage (*Brassica oleracea*)  $1770$ - $\mu$ mol TE/100g, strawberry (*Fragaria ananassa*)  $1540$ - $\mu$ mol TE/100 g, and spinach (*Spinacia oleracea*)  $1260$ - $\mu$ mol TE/100 g.

The DPPH assay was determined to measure the antioxidant capacity of the fruit to trap highly reactive free radicals that can cause deterioration reactions such as peroxidation and oxidative stress; these antioxidants in the fruit have the function of inhibiting the initiation reactions and preventing propagation by being donors of hydrogen atoms or electrons that convert the

resulting products more stable [51, 52].

## VI. CONCLUSION

The results reported in this study confirm that the red Pitahaya *Hylocereus undatus* (Haworth) Britton & Rose grown on the Peruvian coast is an important source of nutrients such as fiber, total carbohydrates, vitamin C, betalains, and phenolic compounds. The DPPH assay revealed a high antioxidant activity comparable to other fruits, so the information obtained in this research could help to establish the commercial potential of this cultivar to be used as a reliable source of natural nutrients and to incorporate it into food formulas that help to maintain health.

### A. Limitations of the Study

*Experimental design:* The study did not consider factors such as season, climate, or soil in the evaluation of the nutritional composition.

*Geographical origin:* This investigation focused on red Pitahaya cultivated on the Peruvian coast, which necessitates Pitahaya cultivation in alternative geographical regions.

*Pitahaya variety:* Only the *Hylocereus undatus* variety was evaluated, which may not be representative of other varieties. Nevertheless, it is considered one of the most significant within this taxonomic group.

*Non-causal correlation:* The results did not establish a causal relationship between the nutritional and bioactive components of red Pitahaya and its direct health benefits in in vivo studies.

Further research is needed to confirm the results and explore other aspects of red Pitahaya, validate the results in different contexts and populations, and evaluate clinical studies to assess the human health benefits of red Pitahaya.

### B. Future Research

Based on this research, future investigations are proposed as follows:

- Effects of environmental factors on nutritional composition
- Effects of temperature, humidity, and light on the nutritional composition of red Pitahaya
- Analysis of the influence of altitude and soil on the nutritional quality of Pitahaya
- Development of functional products and ingredients
- Development of foods enriched with red Pitahaya
- Evaluation of the stability and bioaccessibility of bioactive compounds in functional products

- Antioxidant and anti-inflammatory effects of red Pitahaya in in vitro and in vivo models
- Evaluation of the antimicrobial and antifungal activities of Pitahaya
- Genetic diversity of red Pitahaya on the Peruvian coast
- Identification of genes related to bioactive compound synthesis in red Pitahaya
- Evaluation of the quality and stability of red Pitahaya during storage and transport
- Effects of red Pitahaya on human health (reduction of oxidative stress, improvement of cardiovascular function)
- Evaluation of the safety and tolerability of red Pitahaya in healthy volunteers

Future research can help deepen our knowledge of red Pitahaya and its potential as a functional ingredient in the food industry.

### C. Recommendations

- Study of Pitahaya crop management in other geographical climates because Pitahaya does not require much water and can adapt well to different climatic conditions
- Use of red Pitahaya peel as a natural colorant in the food industry

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## DECLARATIONS

### Author Contributions

Conceptualization, A.J.O.-L.R. and S.A.-C.; methodology, M.B.-R.; formal analysis, A.J.O.-L.R.; investigation, M.B.-R.; data curation, A.J.O.-L.R.; writing—original draft preparation, M.B.-R. and S.A.-C.; writing—review and editing, A.J.O.-L.R.; supervision, M.B.-R.; project administration, A.J.O.-L.R. All authors have read and agreed to the published version of the manuscript.

### Data Availability Statement

The data presented in this study are available on request from the corresponding author.

### Conflicts of Interest

The authors declare no conflict of interest.

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