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Original Article

Effect of Hot Air Drying on Total Phenolic Content and Antioxidant Capacity of Red Pitahaya (*Hylocereus guatemalensis*) Peel

Efecto del secado con aire caliente en el contenido de fenólicos totales y capacidad antioxidante de la cáscara de pitahaya roja (Hylocereus guatemalensis).

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ABSTRACT

Red pitahaya peel (*Hylocereus guatemalensis*) is a by-product of pulp and juice production, which is often underutilized due to limited scientific information on preservation methods that minimally affect its bioactive compounds. The objective of this study was to evaluate the effect of hot air drying on the total phenolic content (TPC) and antioxidant capacity (AC) by DPPH radical scavenging (%) of red pitahaya peel. The peel was separated from the pulp, cut into four equal parts, and dried using hot air. Drying was performed at temperatures of 40, 50, 60, 70, 80, and 90°C for 1,080 minutes. The peel was ground (particles < 850 µm), and the extract (50 mg/ml) was obtained using 80% methanol as a solvent. TPC and AC were then determined. The influence of drying temperature was significant ($p < 0.05$) for both TPC and AC. As the drying temperature increased from 40 to 90°C, TPC values ranged from 116.7 ± 26.0 to 328.8 ± 57.5 mg gallic acid equivalent (GAE) per 100 g of dry peel (dry basis), and AC increased from 22.22 ± 0.06% to 50.00 ± 0.12% DPPH radical inhibition. These results indicate that hot air drying at temperatures between 50 and 90°C can be used to obtain low-moisture red pitahaya peel while preserving its TPC and AC.

Keywords: By-product, antioxidant, bioactive compounds, dehydration, dragon fruit.

RESUMEN

La cáscara de pitahaya roja (*Hylocereus guatemalensis*) es un subproducto de la producción de pulpa y jugo, que muchas veces no es aprovechada por la escasa información científica sobre la forma de conservación que afecte mínimamente sus compuestos bioactivos. El

objetivo de este estudio fue evaluar el efecto del secado con aire caliente en el contenido de fenólicos totales (CFT) y capacidad antioxidante (CA) por secuestro del radical DPPH (%) de la cáscara de pitahaya roja. La cáscara fue separada de la pulpa, cortadas en cuatro partes iguales y colocadas a secar con aire caliente. El secado fue realizado utilizando temperaturas de 40, 50, 60, 70, 80 y 90 °C durante un tiempo de 1 080 min. La cáscara fue molida (partículas < 850 μm), el extracto (50 mg/ml) fue obtenido usando metanol al 80 % como disolvente y el CFT y la CA fueron determinados. La influencia de la temperatura de secado fue significativa ($p< 0,05$) en el CFT y CA, a medida que la temperatura de secado se incrementó de 40 a 90 °C; los valores de CFT variaron de 116,7 ± 26,0 a 328,8 ± 57,5 mg equivalente de ácido gálico/100 g de cáscara seca en base seca y la CA también aumentó de 22,22 ± 0,06 a 50,00 ± 0,12 % de inhibición de radical DPPH. Estos resultados indican que el secado con aire caliente a temperaturas de 50 a 90 °C puede ser usado para obtener cáscara seca de pitahaya roja con baja humedad libre y sin afectar el CFT y CA.

Palabras clave: Subproducto, antioxidante, compuestos bioactivos, deshidratación, fruta del dragón.

INTRODUCTION

Pitahaya or pitaya, also known as "dragon fruit," is a climbing perennial cactus of the *Hylocereus* genus, native to Central America (southern Mexico, Guatemala, and Costa Rica). The species include *Hylocereus guatemalensis, Hylocereus polyrhizus* (or *monacanthus*), *Hylocereus undatus*, and *Hylocereus megalanthus* (Arivalagan *et al.*, 2021; Mercado-Silva, 2018). Due to its vibrant color, sweet taste, and nutritional and functional properties of the pulp, global production has been rapidly increasing (Mercado-Silva, 2018). The main countries cultivating *Hylocereus* are Vietnam, China, Mexico, Colombia, Nicaragua, Ecuador, Thailand, Malaysia, Indonesia, Australia, the United States (Arivalagan *et al.*, 2021), and Peru.

Species within the *Hylocereus* genus differ in pulp and peel color. The fruit of *H. undatus* has white pulp and pink skin, *H. polyrhizus* (or *monacanthus*) has red pulp and pink skin, *H. costaricensis* has violet-red pulp and pink skin, *H. guatemalensis* has red pulp and reddish-orange skin (Figure 1a), and *H. megalanthus* has white pulp and yellow skin (Arivalagan *et al*., 2021). During red pitahaya juice production, a significant amount of peel is discarded, representing 18–33% of the total fruit weight. If not utilized properly, this biowaste can contribute to environmental pollution. The red pitahaya peel is an important source of phytochemicals and natural pigments with antioxidant properties, which could be converted into a high-value functional ingredient (Bassey *et al.*, 2024; Fathordoobady *et al.*, 2019; Qin *et al.*, 2020; Xu *et al.*, 2024). However, its high water content (82.91%) results in a short shelf life (Bassey *et al.*, 2024). Therefore, the unique characteristics of red pitahaya peel have led to interest in developing preservation methods that can extend its shelf life.

Drying is one of the most widely used methods for preserving agricultural products. It extends shelf life by removing

water content, allowing the product to become microbiologically stable, reducing chemical deterioration reactions, and lowering transportation and storage costs (Berk, 2018; Bahnasawy & Shenana, 2004).

Red pitahaya peel can be dried using non-conventional technologies, such as near-infrared drying, mid-infrared drying, far-infrared drying, and microwave drying (Bassey *et al.*, 2024; Chew & King, 2019). These advanced drying techniques offer benefits such as energy efficiency, rapid drying time, optimal product quality, and environmental sustainability (Bassey *et al.*, 2024). However, despite the limitations of conventional drying methods such as long drying times and degradation of heat-sensitive bioactive compounds non-conventional technologies remain expensive and require specialized equipment. For this reason, industries in developing countries still prefer hot air drying, which is low-cost and simple. In this process, raw materials are directly exposed to hot air in a drying chamber (Quan *et al.*, 2024). However, the drying temperature can affect the total phenolic content (TPC) and antioxidant capacity (AC) of red pitahaya peel.

Several studies have evaluated the hot air drying of pitahaya peel from the *H. polyrhizus* species (Bassey *et al.*, 2024; Quan et al., 2024) and *H. undatus* species (Amorim *et al.*, 2023; Santos *et al.*, 2017). However, to date, no studies have been reported on the drying of red pitahaya peel from the *H. guatemalensis* species. This study aimed to evaluate the effect of hot air drying temperature (40, 50, 60, 70, 80, and 90°C) on the TPC and AC of red pitahaya peel (*Hylocereus guatemalensis*).

MATERIALS AND METHODS

Raw Material

Red pitahaya fruits (*Hylocereus guatemalensis*) (Figure 1a) were obtained from Fundo Santa Elena, located in Huaral, Peru.

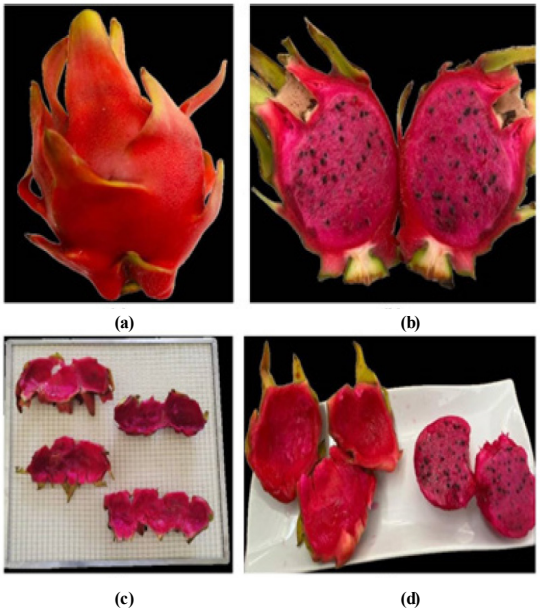

Figure 1. Red pitahaya (H. guatemalensis): a) fruit, b) fruit cut in half, c) peel and pulp and d) peel in 4 parts

Preparation of Raw Material

The fruit was washed with potable water and disinfected using a 4% ppm sodium hypochlorite solution. The peel was separated from the pulp by cutting the fruit in half (Figures 1b and 1c). The peel was then cut into four equal parts and placed on drying trays (Figure 1d).

Drying Process

The drying of red pitahaya peel (*H. guatemalensis*) was conducted using a forced-air dehydrator (AISTAN, model ST04, China). Approximately 300 g of peel, cut into four parts (Figure 1d), was dried at 40, 50, 60, 70, 80, and 90°C for 1,080 minutes, based on preliminary tests. The air velocity was set at 2.5 m/s, and

each temperature condition was tested in triplicate.

Grinding and Sieving of the Dried Peel

The dried pitahaya peel obtained at different temperatures was individually ground using a blade mill for 3 minutes. Subsequently, the ground peel was passed through an 850 µm sieve. The dried and milled peels that passed through the sieve were then stored in airtight bags for further use.

Extraction of Peel Extracts

The extracts were obtained following the method reported by Cornelio-Santiago *et al.* (2019) with some modifications. Approximately 2 g of dried and ground red pitahaya peel was mixed with 40 ml of 80% methanol in a 250 ml container. The mixture was homogenized using a magnetic stirrer at 1,000 rpm for 20 minutes at room temperature. After homogenization, the mixture was centrifuged at 4,500 rpm for 20 minutes, and the supernatant (solutes + solvent) or extract was collected.

Determination of Total Phenolic Content (TPC)

TPC was determined using the methodology described by Cornelio-Santiago *et al.* (2019). Each extract obtained was diluted with 80% methanol at a 1:19 (v/v) ratio—meaning 100 µl of each extract was mixed with 1,900 µl of 80% methanol in a Vortex mixer at 2,000 rpm for 1 minute.

In a 10 ml glass tube, 1.364 ml of distilled water, 300 µl of the previously diluted extract, and 136 µl of Folin-Ciocalteu reagent were added and gently homogenized. The mixture was then allowed to stand for 8 minutes at room temperature in a dark space. After the resting period, 1.2 ml of 7.5% Na_2CO_3 solution was added, lightly homogenized, and left to stand for 2 hours at room temperature in a dark space.

The absorbance readings were performed using a UV/VIS spectrophotometer (Genesys 150, Thermo Scientific, EU) at 760 nm. The equation $y = 0.0166x + 0.0129$ ($R^2 = 0.9991$), obtained from a standard gallic acid curve at different concentrations (10, 20, 30, 40, 50, and 60 µg/ml), was used to calculate the TPC in the different extracts. The results were expressed as mg gallic acid equivalent (GAE) per 100 g of dried peel.

Determination of Antioxidant Capacity (AC)

The antioxidant capacity was determined using the methodology described by Tian *et al.* (2018) with some modifications. 100 µl of each extract (50 mg/ml) was mixed with 2 ml of 0.08 mol/L DPPH solution in ethanol. The mixture was allowed to react for 40 minutes before measuring the absorbance at 517 nm. A 0.08 mol/L DPPH solution in ethanol was used as the control, and ethanol was used as the blank. The DPPH radical scavenging capacity was calculated as the percentage of inhibition using the following equation: $\%\ \text{inhibition} = (1 - A_{sample}/A_{control}) \times 100$.

Statistical Analysis

The data obtained in each experiment were subjected to analysis of variance (ANOVA) and Tukey multiple comparison test with a 95% confidence level. The statistical analyses were performed using STATGRAPHICS (StatPoint, Inc. v.16.1.03). The standard curve was generated using Microsoft Excel MSO (version 2021).

RESULTS AND DISCUSSION

Effect of Drying Temperature on Free Moisture Content of Red Pitahaya Peel

The initial moisture content of red pitahaya peel was 90.41 ± 1.03%. The drying behavior of the peel in terms of free moisture content (kg of water/kg of dry peel) and drying temperature is shown in Figure 2.

The data indicate that 1,080 minutes was sufficient to dry 300 g of red pitahaya peel, achieving free moisture values ranging from 0.0038 to 0.0007 kg of water/kg of dry peel at temperatures from 40 to 90°C, respectively. This confirms that the dried red pitahaya peel obtained at all temperatures can be considered a dehydrated product (Ibarz & Ribas, 2005). This condition ensures microbiological stability, reduces chemical deterioration reactions, and lowers transportation and storage costs (Bahnasawy & Shenana, 2004).

Additionally, the moisture content was well below the maximum limit of 15% established for dried and milled food products (Codex Alimentarius, 1985).

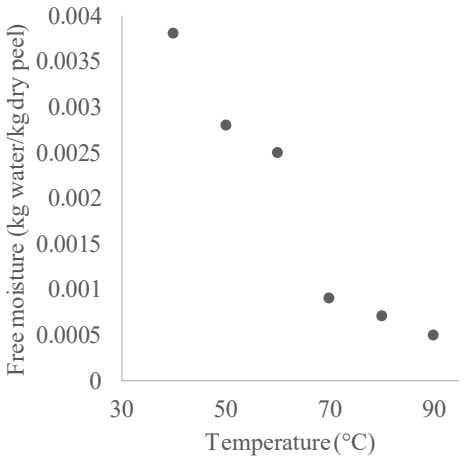

Figure 2. Drying behavior of red pitahaya peel in terms of free moisture content (kg of water/kg of dry peel) and drying temperature

In another study, a longer drying time of 640 minutes was required to dehydrate 100 g of red pitahaya peel of the species *H. polyrhizus*, reaching a moisture content below 0.2, when 50°C and an air velocity of 0.2 m/s were used (Bassey *et al.*, 2024). This outcome is expected since the air velocity was much lower compared to the 2.5 m/s used in this study. On the other hand, drying times of 500, 415, and 385 minutes were necessary to obtain dried red pitahaya peel of the species *H. undatus* at temperatures of 50, 60, and 70°C, respectively, achieving moisture levels of 5.39%, 5.27%, and 4.40%, with an air velocity of 1.5 m/s (Santos *et al.*, 2017). Additionally, *H. undatus* red pitahaya peels required 390 minutes to reach a constant moisture content at 60°C (Amorim e*t al.*, 2023). These different results may be related to variations in the water content of red pitahaya peel, as evidenced by the lower moisture value (82.91%) reported for *H. polyrhizus* (Bassey *et al.*, 2024) and the higher moisture value (93.38%) for H. undatus (Santos *et al.*, 2017). In comparison with the moisture level obtained in this study, it is likely that the water content or moisture level is influenced by the species of the *Hylocereus* genus and the physiological or commercial ripeness of the studied fruits.

Effect of Drying Temperature on Total Phenolic Content (TPC)

The TPC was determined in red pitahaya peels subjected to different drying temperatures (40, 50, 60, 70, 80, and 90°C), and the results are shown in Table 1. The TPC values ranged from 116.7 ± 26.0 to 328.8 ± 57.5 mg GAE/100 g of dry peel for temperatures between 40 and 90°C, respectively. These results indicate

that there was no significant difference ($p < 0.05$) in TPC for drying temperatures between 50 and 90°C, but a significant difference was observed when compared to the temperature of 40°C. However, in general, the drying temperature resulted in an increase in TPC in dried red pitahaya peel. This increase was likely due to the concentration of the compounds as drying temperature increased. Additionally, higher temperatures may cause the breakdown of covalent bonds, leading to the release of phenolic compounds (Bassey *et al.*, 2024), which would explain the higher TPC observed in peels dried at 50 to 90°C.

On the other hand, the lower TPC value observed in red pitahaya peel dried at 40°C may have been influenced by the prolonged drying duration, which resulted in the release of phenolic compounds followed by their decomposition due to the presence of polyphenol oxidase, a heat-resistant enzyme that is inactivated at temperatures above 60°C (An *et al.*, 2023; Onwude *et al.*, 2022).

Other studies have reported different TPC values compared to this study (Table 1). For example, *H. polyrhizus* showed 640.52 mg GAE/100 g at 50°C, while *H. undatus* had 313.96 mg GAE/100 g at 60°C (Amorim *et al.*, 2023). This indicates that the species itself may also influence TPC levels.

Effect of Drying Temperature on Antioxidant Capacity (AC)

Table 1 presents the results of the antioxidant capacity (AC) determination in red pitahaya peels dried at different temperatures (40, 50, 60, 70, 80, and 90°C) using the DPPH Scavenging Assay Protocol. The antioxidant capacity, expressed as the percentage of inhibition, ranged from 22.22 ± 0.06% to 50.00 ± 0.12%, corresponding to drying temperatures from 40 to 90°C.

Table 1.
Effect of hot-air drying temperature on total phenolic content and antioxidant capacity of red pitahaya peel

Temperature (°C)	Total Phenolic Content (mg GAE/100 g of dry peel, dry basis)	Antioxidant Capacity (% DPPH radical inhibition)
40	116.7 ± 26.0 ^{b}	22.22 ± 0.06 ^{b}
50	250.8 ± 42.4 ^{a}	29.87 ± 0.07 ^{ab}
60	279.0 ± 38.4 ^{a}	30.53 ± 0.10 ^{ab}
70	257.3 ± 9.7 ^{a}	41.86 ± 0.08 ^{ab}
80	279.8 ± 25.4 ^{a}	49.84 ± 0.04 ^{a}
90	328.8 ± 57.5 ^{a}	50.00 ± 0.12 ^{a}

Data are expressed as mean ± standard deviation. The same superscripts within each column indicate no significant difference ($p < 0.05$) according to Tukey's range test.

As the drying temperature increased, the percentage of inhibition also increased. However, there was no significant difference in inhibition percentages for drying temperatures between 40 and 70°C. Significant differences were observed when comparing inhibition percentages obtained at 80 and 90°C. These two temperatures showed the highest inhibition values: 49.84 ± 0.04% at 80°C and 50.00 ± 0.12% at 90°C. Meanwhile, the lowest inhibition percentage (22.22 ± 0.06%) was recorded at 40°C. The DPPH radical inhibition percentage is directly related to the presence of phytochemicals, such as tannins, flavonoids, phenolic acids, and betalains (Luu *et al.*, 2021). Thus, the increase in the inhibition percentage of dried red pitahaya peels at 40, 50, 60, 70, 80, and 90°C may be due to better retention of phytochemicals as temperature increases, as demonstrated by the increase in TPC values (Table 1).

On the other hand, lower inhibition percentages may be associated with the reduced retention of antioxidant compounds, such as ascorbic acid, a thermolabile compound that degrades with increasing temperature. Additionally, while some phytochemicals are lost due to heat treatment, others are released through bond breakdown and loosening of covalent linkages (Bassey *et al.*, 2024). As a result, the drying process does not have the same effect on the antioxidant capacity of different biological matrices. This phenomenon explains the variations in DPPH inhibition percentages found in different drying studies of red pitahaya peel, such as: 75% inhibition at 100°C (Chew & King, 2019), 36.98% at 50°C (Bassey *et al.*, 2024), 13.18% at 65°C (Quan *et al.*, 2024) and 83.48% at 70°C (Nurliyana *et al.*, 2010).

CONCLUSION

It was observed that drying temperature influences the increase in TPC and AC in red pitahaya peel (*H. guatemalensis*). Temperatures between 50 and 90°C resulted in better retention of TPC, which in turn increased antioxidant capacity (DPPH radical inhibition percentage). As drying temperature increased, TPC values (116.7 ± 26.0 to 328.8 ± 57.5 mg GAE/100 g of dry peel) and antioxidant capacity (22.22 ± 0.06% to 50.00 ± 0.12%) also increased.

Finally, the results indicate that hot-air drying at temperatures between 50 and 90°C can be used to obtain dried red pitahaya peel with low free moisture content without compromising total phenolic content and antioxidant capacity. Additionally, these results provide a foundation for further studies on dried and ground red pitahaya peel (*H. guatemalensis*) in terms of oil and water solubility and its application in functional food formulations.

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