Red prickly pear fruit (*Opuntia ficus-indica*) and its potential use in northwestern Mexico

TUNA ROJA (*Opuntia ficus-indica*) Y SU POTENCIAL APROVECHAMIENTO EN EL NOROESTE MEXICANO

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Abstract

Prickly pear fruits, pulp and peel, are rich sources of important nutrients and bioactive compounds, such as polyphenols (mainly gallic and chlorogenic acid), flavonoids (catechins) and betalains, as well as ascorbic acid. Therefore, the fruit is appreciated for its nutritional value, and health benefits. Especially, it has been recommended for its good effects on diseases such as cancer, cardiovascular diseases and diabetes, which are directly related to reactive oxygen species. Due to their high sugar content, the fruits can be used as raw material in many products, from fresh consumption, processed in jams, or in alcoholic beverages. They are also used as natural sweeteners or colorants, and as a supplement in probiotic foods. In addition, prickly pear by-products have been studied for ruminant feed as a source of digestible dietary fiber. Although the largest production of this fruit is in the center and south of the country, in the northwest they grow wild and are not cultivated commercially. On the other hand, the limited water availability in this area and the prevailing ecological conditions make it feasible to consider it as a crop of interest. This review focused on the integral valorization of the red prickly pear fruit (*Opuntia ficus-indica*) and its potential utilization in northwestern Mexico.

Keywords: Red prickly pear, utilization, by-products..

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Resumen

Los frutos de tuna, pulpa y cáscara, son ricas fuentes de importantes nutrientes y compuestos bioactivos, como polifenoles (principalmente ácido gálico y clorogénico), flavonoides (catequinas) y betalaínas, así como de ácido ascórbico. Por ello, la fruta es apreciada por su valor nutritivo y sus beneficios a la salud. Especialmente, se ha recomendado por sus buenos efectos en enfermedades como el cáncer, enfermedades cardiovasculares y diabetes, las cuales se relacionan directamente con las especies reactivas al oxígeno. Debido a su alto contenido en azúcares, los frutos pueden utilizarse como materia prima en muchos productos, desde consumo en fresco, procesados en mermeladas, o en bebidas alcohólicas. También se utilizan como edulcorantes o colorantes naturales y como suplemento en alimentos probióticos. Además, se han estudiado a los subproductos de la tuna para alimento de rumiantes como fuente de fibra dietética digestible. Aunque la mayor producción de este fruto se tiene en el centro y sur del país, en el noroeste crecen de forma silvestre y no se cultivan comercialmente. Por otro lado, la limitada disponibilidad de agua en esta zona y las condiciones ecológicas prevalecientes hacen factible considerarlo como un cultivo de interés. Esta revisión se enfocó en la valorización integral del fruto de la tuna roja (*Opuntia ficus-indica*) y su potencial aprovechamiento en el noroeste de México.

Palabras clave: Tuna roja, aprovechamiento, subproductos..

INTRODUCTION

In many countries Prickly Pear Fruit (PPF) are known for its nutritional and health benefits due to its bioactive compounds, primarily polyphenols, flavonoids, and pigments such as betalains. Betalains are water-soluble pigments that in vivo and in vitro studies have shown to be a promising alternative to supplementing therapies in oxidative stress, inflammation, and dyslipidemia-related diseases such as stenosis of the arteries, atherosclerosis, hypertension and cancer, among others (Rahimi *et al*., 2018). Basied on of such nutraceutical properties, PPF varieties like "Agostani", which have limited commercial value, could be processed to value-added products, such as juice, puree and concentrate. These products can be widely used in preparation of beverages, ice cream, yogurt, milkshakes, jams, jellies, smoothies and many other food products (Palmeri *et al*., 2020). Such is the case of the red PPF that grows naturally in northwestern Mexico. Therefore, the largest volume of production of PPF is concentrated in the States of Mexico, Puebla, and Zacatecas. These tuna-producing areas have economically exploited both fresh and processed products. Additionally, during processing, the peels and seeds from PPF are usually discarded. These "waste" products contain valuable bioactive compounds (De Wit *et al*., 2020). This work provides a general review of the integral use of prickly pear fruit, offering a theoretical basis of reference to highlight the importance of the use of this fruit in Sonora, México.

General aspects of prickly pear fruit

Prickly pear belongs to the *Cactaceae* family and is specially produced in semi-arid, and arid regions where water is limited in terms of agriculture (Abdel-Hameed *et al*., 2014). The fruit of *Opuntia ficus-indica* L. Mill. (commonly known as prickly pear) develops from the stem tissues of an inferior ovary (Figure 1). It matures approximately 110 to 120 days after blossoming and can weigh between 80 to 200 g. Prickly pears (PP) are cylindrical or ovoid in shape, measuring 5 to 10 cm in length and 4 to 8 cm in width. The fruit consists of three main components: peel, pulp, and seeds. The peel constitutes 30 to 40% of the total weight, the pulp 60 to 70%, and the seeds 2 to 10% (Inglese *et al*., 2017; Martins, Ribeiro, and Almeida, 2023). The PP peel is separated into two parts: pericarp and mesocarp. The pericarp is thin and resembles cladodes, while the mesocarp is edible and nutritious. However, when the fruit is peeled, the mesocarp is discarded and rarely consumed (Aruwa, Amoo, and Kudanga, 2018; Martins, Ribeiro, and Almeida, 2023b). The peel is Green during the early stages of fruit growth, changing to diverse colors ranging from greenish-white to purplish, and can be orange, purple, yellow, red, or purplish as the fruit matures. The diverse coloration of cactus fruits is attributed to their ecological and genetic diversity (Sáenz *et al*., 2013; Aruwa, Amoo, and Kudanga, 2018). The edible part is the PP pulp, which is rated as soft, succulent, transparent, viscous and silky. The pulp contains numerous small seeds with hard integuments, and its color matches that of the peel. The seeds, which are evenly distributed throughout the fruit, are black, edible, and have been extensively studied.

Figure 1
Opuntia ficus-indica cactus plant or nopal (A), and red prickly pear fruit (B) of Sonora, México.

In Sonora, northwestern Mexico, due to the limited availability of water for crop production, it is necessary to establish crops that are more in line with the prevailing ecological conditions, as is the case of cactus pear or "nopal" (Robles-Contreras, Macías-Duarte and Grijalva-Contreras, 2008). The fruit of the PP cactus plant is widely consumed in Mexico mainly during the harvest season from April to November, with the highest production between July and September. Therefore, the value of prickly pear production increased by 13.27% from 2019 with a value of 1,537 million Mexican pesos to 2023 with 1,741 million (SIAP, 2024). Of the 16 states in Mexico where PPF is grown, the most important in terms of production volume are the State of Mexico, Puebla and Zacatecas. In addition, 97% of national production is in rainfed mode and only eight states produce PPF in irrigated mode (Agro Orgánico, 2023; SIAP, 2024). As for the state of Sonora, there are no production reports in the database of the federal agency "Servicio de Información Agroalimentaria y Pesquera" (SIAP). However, PPF, specifically red or Mexican pink, is found in the wild even in urban areas. For this geographical area of the country, and considering its climate, the opportunity for production of this fruit could be in rainfed mode.

Whole fruit applications

Currently, the demand for the consumption of functional foods and nutraceuticals has increased (Esteem research, 2023; Siddique *et al.*, 2024). This demand leads to the search for new alternative uses, and integral utilization of fruits. Such is the case PPF. This fruit is relevant for its nutritious (Table 1, and 2) and health-improving values (Duque-Buitrago *et al.*, 2024), especially by its good effects on diseases such as cancer, cardiovascular diseases, and diabetes which are directly related to reactive oxygen species (Abdel-Hameed *et al.*, 2014; Andreu *et al.*, 2018) (Figure 2). The PPF are consumed as fresh vegetables, added to casseroles, cooked, canned, or used in salads (Muñoz de Chávez *et al.*, 1995). Due to its high sugar content, PPF can be used as

raw materials in many products from fresh or jam to alcoholic beverages by end consumers (Eroglu *et al*., 2021). Moreover, this fruit have high sugar content and that is why it is used in several products such as jam, alcoholic beverages, and natural liquid sweeteners (Pinedo Espinoza *et al*., 2017; Andreu *et al*., 2018). PPF juice can also be used for the production of vinegar owing to its richness in fermentable sugars. This production of a new type of vinegar from prickly pear juice opens an alternative method for a new product in the market and can add value through a simple process that can be applied at different industrial scales (Prieto *et al*., 2009; Es-sbata *et al*., 2023). Fouad *et al*. (2022), determined the chemical characteristics of fresh juice and peel of *Opuntia ficus-indica* (yellow cultivar) and *Opuntia* littoralis (red cultivar), using them in cookies production and evaluating the quality of cookies. Results showed yellow and red juice cookies possessed higher moisture. Yellow or red peel cookies owned higher crude fiber. Yellow and red peel cookies recorded the best microbiological quality. Peel cookies had higher weight and hardness compared to juice cookies which had higher diameters and spread ratio. All produced cookies, are organoleptically accepted. The results suggested that, fresh prickly pear juices and peels could be used in the production of delicious and healthy cookies. The PPF has also been used to prepare functional beverages made from a combination of *Agave* sap and PPF juice to analyze for its nutrients and bioactive and potentially health-promoting compounds. The beverage was evaluated for its ability to act as an antioxidant, regulate glycemic properties, and undergo gut bacterial fermentation in vitro (Duque-Buitrago *et al*., 2024). Eseberri *et al*. (2024), analyzed the triglyceride-lowering effect of PPF peel and pulp extracts obtained from fruits of three varieties (Pelota, Sanguinos, and Colorada) in 3T3-L1 maturing and mature adipocytes. They found the betalain and phenolic-rich extracts from PPF might serve as an effective tool in obesity management. PPF peels should be included in processed products such as juice, dried fruit and chutneys. These processed products are multi-component food ingredients and are therefore multi-component nutraceuticals, which retained their antioxidant properties (De Wit *et al*., 2020). Regarding the use of PP seeds, oil from them has been known for its nutritive value and can be potentially used for health promotion (Al-Naqeb *et al*., 2021). Similarly, Karabagias *et al*. (2020) had already observed that pure PP seeds oil had a high in vitro antioxidant activity (84 ± 0.010%) and total phenolic content (551 ± 0.300 mg of gallic acid equivalents/L). PP seeds oil may be then used as a beneficial by-product, in different food systems as a flavoring, antioxidant, and nutritional agent.

Table 1
Chemical composition and antioxidant activity of prickly pear fruit.

Component (g 100 g^{-1})	Pulp	Peel	Seed	Juice (%)
Moisture	82.29-85.6[1,2]	10.12[5]	3.39[5]	-
Protein	0.20-0.21[1,2]	1.225-8.30*[4]	11.8*[4]-17.34[5]	1.23[3]
Fat	0.12-0.56[2,1]	2.43*[4]-5.04[5]	6.77*[4]-9.65[5]	0.73[3]
Ash	0.44-0.48[2,1]	3.58[5]-12.1*[4]	5.90*[4]-1.79[5]	0.43[3]
Total sugars	12.80[2]	-	-	-
Fructose	26.50±2.08[6]	-	-	-
Glucose	39.32±2.75[6]	-	-	-
Sucrose	0.15±0.01[6]			
Ascorbic acid (µg/g fruit)	201.20±2.03[7]	-	-	-
Total antioxidant (µg FeSO4.7H2O/g)	789.97±18.99[7]	-	-	-
Total phenolic (µg GAE/g fruit)	1,065.8±33.5[7]	-	-	-
Total flavonoid (µg catechin/g fruit)	540.88±31.48[7]	-	-	-

* % w/w, dry matter.
References: 1. Aquino Bolaños *et al.*, 2012. Variety "Moradilla 1"; 2. Ha *et al.*, 2024; 3. Hallim *et al.*, 2019; 4. El Kossori *et al.*, 1998; 5. Albergamo *et al.*, 2022; 6. Özcan *et al.*, 2022; 7. Eroglu *et al.*, 2021.

Table 2
Main fatty acid composition of prickly pear seed oil from Mexico.

Unsaturated fatty acid %			Saturated fatty acid %	
Linoleic	Oleic	Linolenic	Palmitic	Stearic
66.5–76.1	9.3–19.9	NR*	5.6–56.2	15.5–36.1
60.5–78.8	10.7–19.9	NR	2.9–6.10	2.9–5.2

Source: Regalado-Rentería *et al.*, 2020.
* NR not reported.

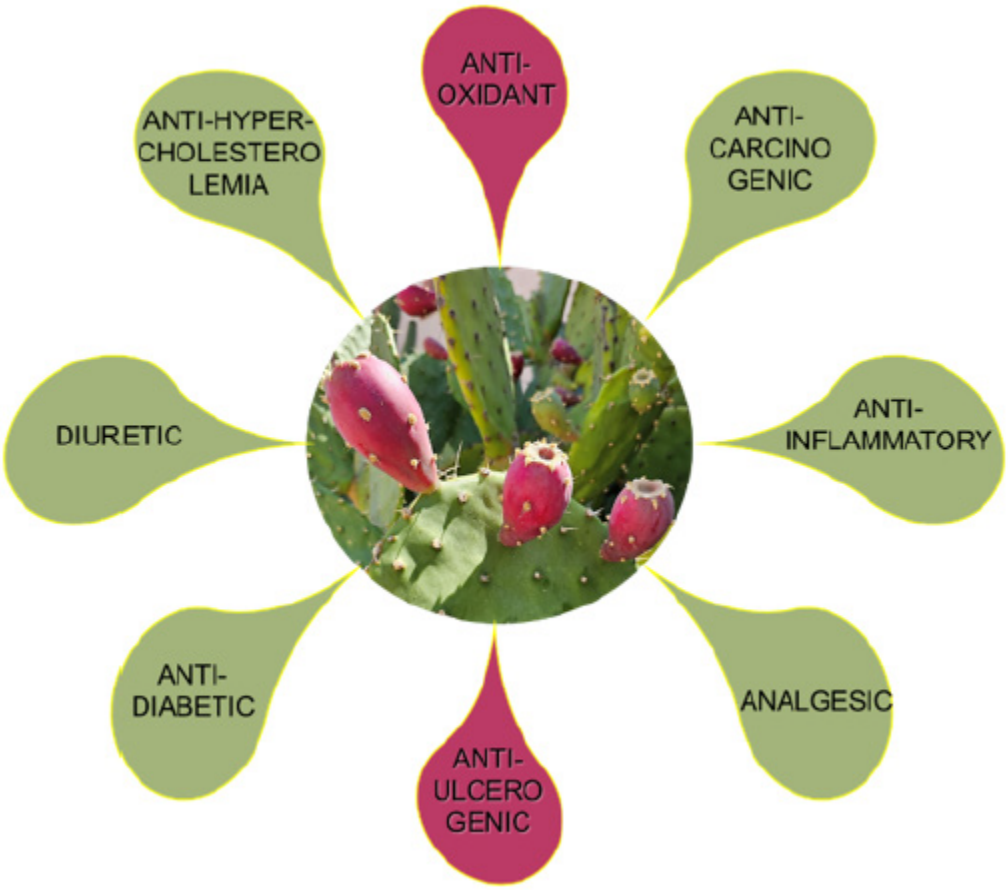

Figure 2
The health benefits of PPF.
Adapted from Ha *et al.*, 2024.

Uses of by-products

Among the by-products used to feed ruminants, waste from the processing of the PP is increasingly present in Sicily. The PP peels obtained following peeling of the fruit intended for fresh consumption and the PP 'pastazzo' obtained from the residue of grinding the whole fruit for the extraction of the juice, consisting of the peel, pulp and seeds (Todaro *et al.*, 2020). After the PP peel has been removed from the fresh fruit, result in a large availability of this agro-industrial by-product, a source of digestible dietary fiber and rich in bioactive compounds (Melgar *et al.*, 2017; Amaya-Cruz *et al.*, 2019). The PP by-products become available at the end of the summer, when fresh forage resources are practically non-existent and could represent a source of water and digestible fiber for ruminants (Morshedy *et al.* 2020). PP accounts for about 30% of the fruit weight (Melgar *et al.*, 2017). However, PP by-products, due to the high level of moisture and fermentable carbohydrates, it cannot be stored as such for long periods. It is therefore necessary to find alternative solutions for its conservation. Ensilage, a widely practiced preservation technique, is a promising solution for the preservation and utilization of PP by-products due to the anaerobic fermentation process it involves. This technique has also been suggested to conserve both cladodes (Matias *et al.*, 2020), and PP (Vastolo *et al.*, 2020). Likewise, other studies have reported the use of PP peel in animal feed formulations (Gannuscio *et al.*, 2024). Coronado-Contreras *et al.* (2023), used PP peel residues as a substrate in solid-state fermentation to obtain bioactive compounds. They found that fermented extracts showed a higher antioxidant activity compared to the unfermented extracts. They conclude that use of solid-state fermentation processes facilitates the

accumulation of hydrolyzable and condensed tannins with *Aspergillus* sp., which can be applied in different industrial sectors due to the antioxidant and antimicrobial activity.

Aspects that reduce prickly pear fruit quality

The common practice is for the fruits can be successfully commercialized as a ready-to-eat product, or processed for multiple uses. Although the nutritional value, flavor and taste of fruits improve during the ripening period, they generally become more susceptible to various physiological disorders and severe quality losses after harvest. To preserve the quality characteristics of PPF after harvest, it will be desirable to advance or delay harvest depending on its intended use (Eroglu *et al*., 2021). Because PP has a limited shelf life (3-4 weeks), it is not suitable for long-term storage or worldwide distribution (Feugang, 2006; Nesreen, 2013). They are highly perishable, and usually after nine days of storage at ambient temperature (19 ± 5 °C), the fruit can show spots and rotting due to decay (Hahn-Schlam, Valle-Guadarrama, and Jenkins, 2019). This fruit is classified as a non-climacteric fruit, in which cold storage reduces the respiration rate and fruit mass loss, inhibits the growth of microorganisms, and prolongs shelf life (Crisosto and Mitchell,1992). The fruit is very sensitive to low storage temperatures (5 °C) which cause chilling injuries (Scalone *et al*., 2012), although Andreu-Coll *et al*. (2021), in the 'Orito' cultivar, found that storage under cold conditions (2 °C, 85–90% HR) maintained fruit quality parameters in optimal values for up to 28 days. According to Yahia (2012), the PP can be kept for 2 to 5 weeks at 5 °C to 8 °C with 90% to 95% RH. Moreover, the main limit to its production is the formation of off-flavours due to different factors, such as the growth of microorganism and the action of endogenous enzymes (lipid oxidation). In fact, the oxidoreductases are directly responsible for the lipid oxidation, which has influence on the production of off-flavours, on the structure and on the shelf-life of the fruit (Scalone *et al*., 2012). Technologies such as the use of modified and passive atmospheres (Díaz-Delgado *et al*., 2022) have been used to preserve their nutritional properties (Scalone *et al*., 2012). Using this technology, Karabagias *et al*. (2019), but in prickly juice, they extended the shelf life by 5 days in vacuum compared to air packaging. The treated fruit proved to be a rich source of phytochemicals and natural antioxidants (AA of 67.33 ± 5.89-75.63 ± 4.41% and total phenolic content of 3234.5 ± 978.2-7592.1 ± 2441.0 mg GAE L-1), relative to the untreated fruit ($p<0.05$). Other studies to maintain the quality of PP include the effect of storage at different temperatures (Allegra *et al*., 2015; Cruz-Bravo *et al*., 2019), use of UVB light (Ortega-Hernández, Welti-Chanes and Jacobo, 2018), and cryocauterization (Hahn-Schlam, Valle-Guadarrama, and Jenkins, 2019). However, the success of storage depends on several factors, including the cultivar, storage atmosphere, orchard management practices (especially irrigation and mineral nutrition), and fruit maturity stage (Zegbe, Serna and Mena, 2015). In regions where the fruit grows wild and there are no orchard management practices, quality characteristics may be compromised.

Future opportunities and challenges with PPF

In the central and southern regions of Mexico, various events such as fairs, festivals, and exhibitions are held to promote a product or service and provide producers with access to the economic benefits from visitors to these events. Additionally, these events aim to incentivize interest from both the general public and governments to support them, thereby fostering the growth of this industry. Regarding prickly pears, events such as the National Prickly Pear Fair in San Martín de las Pirámides, State of Mexico, Expo Nopal-Tuna in Milpa Alta, Mexico City, the Prickly Pear and Nopal Festival in Teotihuacán, State of Mexico, the Prickly Pear and Pitaya Festival in Huitzuco, Guerrero, and the National Meeting of Prickly Pear Producers in Zacatecas, Zacatecas, are held. Additionally, there is the specific Red Prickly Pear Fair in Villanueva, Zacatecas. All these events highlight the local production of prickly pears and *nopales*, promoting cultivation techniques and regional varieties. They are commonly accompanied by cultural and tasting events, as well as conferences,

workshops, and contests. This reflects how these events not only celebrate the prickly pear as an agricultural product but also its cultural, economic, and social importance for the producing communities (Muñoz, 2024). In Sonora, there is experience with fairs and festivals for various products developed in the region such as asparagus, grapes, pecans, olives, and even pitaya. This experience could be leveraged for the rapid acceptance and development of the prickly pear product system. Although there are about 14 cultivars of prickly pear in Mexico, only eight varieties are produced commercially. The main ones are Alfajayucan (34%), Roja Lisa (21%), Blanca Cristalina (17%), Criolla (16%), and Amarilla (8%), with most of them having white pulp, followed by red and finally yellow (Fernández *et al*., 2000; SIAP, 2024). The red variety is particularly valued for having few spines, which is appreciated by the international market and also facilitates its handling (Fernández *et al*., 2000). Sonora has a wide variety of ecosystems and climates that make it possible to cultivate various products, including prickly pear cactus. The state has suitable soil conditions and a minimum annual precipitation of 300 mm, as well as medium-textured soils with good fertility (SAGARPA, 2015). The potential for export is significant; however, due to the generated profits, some producers are preferring to work with vegetable *nopales*. Bonilla *et al*. (2020), mention that it is essential to ensure the preservation of the production of both products to maintain this typical and highly nutritious food for future generations. On the other hand, *Opuntia* cultivations fulfil ecosystem protection functions by serving as habitats for a diverse range of living organisms, supplying raw material for soil development, offering protection against erosion and potentially participating in phytoremediation processes for contaminated water and soil (Stavi, 2022). One possible use of the beneficial properties of PPF is as an ingredient in nutrified foods. This refers to food items that have been enhanced with useful components like vitamins, minerals, probiotics, antioxidants, or plant extracts, providing additional advantages over mere sustenance (Maurya *et al*., 2021). With the application of novel technologies like nano- or micro-sized structures or particles that can encapsulate flavors or nutrients in nutrified foods at particular locations or times or in response to specific stimuli like enzymes, temperature, or pH can be created using 3D printing, nanotechnology, or microencapsulation (Esteem research, 2023). For instance, nanotechnology can create nano-encapsulated PPF nutrients that can improve nutrified foods' delivery, bioavailability, and stability.

CONCLUSIONS

As discussed in this review, there are several benefits to be gained from the integrated use of PPF. Sonora's conditions make it feasible for the plant to be used, for example, in crop rotation. The inclusion of PPF in the local economy would allow the implementation of conservation technologies in the whole or minimally processed fruit, as well as generate new uses of the by-products with high potential like in functional foods, the industry, health and cosmetics.

Conflicts of Interest: The authors declare no conflict of interest.

LITERATURE CITED

Abdel-Hameed, E. S. S., Nagaty, M. A., Salman, M. S., Bazaid, S. A. 2014. Phytochemicals, nutritionals and antioxidant properties of two prickly pear cactus cultivars (*Opuntia ficus-indica* Mill.) growing in Taif, KSA. Food Chemistry, 160, 31–38. https://doi.org/10.1016/j.foodchem.2014.03.060.

Agro Orgánico. 2023. México produce 400 mil toneladas de tuna. Cultivo y producción. Newsletter. Jun. 2, 2023. [Online]. Available: https://agroorganico.info/mexico-produce-400-mil-toneladas-de-tuna/

Albergamo, A., Potortí, A. G., Di Bella, G., Amor, N. B., Lo Vecchio, G., Nava, V., Rando, R., Ben Mansour, H., Lo Turco, V. 2022. Chemical characterization of different products from the Tunisian *Opuntia ficus-indica* (L.) Mill. Foods, 11:155. https://doi.org/10.3390/foods11020155.

Al-Naqeb, G., Fiori, L., Ciolli, M., Aprea, E. 2021. Prickly pear seed oil extraction, chemical characterization and potential health benefits. Molecules, 26, 5018. https://doi.org/10.3390/molecules26165018.

Allegra, A., Sortino, G., Miciletta, G., Riotto, M., Fasciana, T., Inglese, P. 2015. The influence of harvest period and fruit ripeness at harvest on minimally processed cactus pears (*Opuntia ficus-indica* L. Mill.) stored under passive atmosphere. Postharvest Biol. Technol. 104, 57–62.

Aquino Bolaños, E. N., Chavarría Moctezuma, Y., Chávez Servia J. L., Guzmán Gerónimo, R. I., Silva Hernández, E. R., Verdalet Guzmán, I. 2012. Caracterización fisicoquímica de siete variedades de tuna (*Opuntia* spp.) color rojo -violeta y estabilidad del pigmento de las dos variedades con mayor concentración. Ingeniería y Ciencia de la Universidad Autónoma de Aguascalientes. 55:3-10.

Amaya-Cruz, D. M., Pérez-Ramírez, I. F., Delgado-García, J., Mondragón-Jacobo, C., Dector-Espinoza, A., Reynoso-Camacho, R. 2019. An integral profile of bioactive compounds and functional properties of prickly pear (*Opuntia ficus-indica* L.) peel with different tonalities. Food Chem. 278:568–578. doi: 10.1016/j.foodchem.2018.11.031.

Andreu, L., Nuncio-Jauregui, N., Carbonell-Barrachina, A. A., Legua, P., Hernandez, F. 2018. Antioxidant properties and chemical characterization of Spanish *Opuntia ficus-indica* Mill. cladodes and fruits. Journal of the Science of Food and Agriculture, 98(4), 1566–1573. https://doi.org/10.1002/jsfa.8628.

Andreu-Coll, L., García-Pastor, M. E., Valero, D., Amorós, A., Almansa, M. S., Legua, P. Hernández, F. 2021. Influence of Storage on Physiological Properties, Chemical Composition, and Bioactive Compounds on Cactus Pear Fruit (*Opuntia ficus-indica* (L.) Mill.). Agriculture, 11, 62. https://doi.org/10.3390/agriculture11010062.

Aruwa, C. E, Amoo, S. O., Kudanga, T. 2018. Opuntia (*Cactaceae*) plant compounds, biological activities and prospects – a comprehensive review. Food Res Int. 112: 328–344. doi: 10.1016/j.foodres.2018.06.047.

Crisosto, C. H., Mitchell, F. 1992. Postharvest Handling Systems: Small Fruit (Table Grapes, Strawberries, Kiwifruit). In Postharvest Technology of Horticultural Crops; Kader, A. A., Ed.; Publication 3311; University of California Division of Agriculture and Natural Resources: Oakland, CA, USA, pp. 357–374.

Cruz-Bravo, R. K., Guzmán-Maldonado, S. H., Araiza-Herrera, H. A., Zegbe, J. A. 2019. Storage alters physicochemical characteristics, bioactive compounds and antioxidant capacity of cactus pear fruit. Postharvest Biol. Technol. 150, 105–111.

Coronado-Contreras, A., Ruelas-Chacón, X., Reyes-Acosta, Y. K., Dávila-Medina, M. D., Ascacio-Valdés, J. A., Sepúlveda, L. 2023. Valorization of prickly pear peel residues (*Opuntia ficus-indica*) using solid-state fermentation. Foods.12, 4213. https://doi.org/10.3390/foods12234213.

De Wit, M., Du Toit, A., Osthoff, G., Hugo, A. 2020. Antioxidant content, capacity and retention in fresh and processed cactus pear (*Opuntia ficus-indica* and *O.*robusta) fruit peels from different fruit-colored cultivars. Front. Sustain. Food Syst. 4:133. doi: 10.3389/fsufs.2020.00133.

Díaz-Delgado, G. L., Rodríguez-Rodríguez, E. M., Dorta, E., Lobo, M. G. 2022. Effects of Peeling, Film Packaging, and Cold Storage on the Quality of Minimally Processed Prickly Pears (*Opuntia ficus-indica* L. Mill.). Agriculture 2022, 12, 281. https://doi.org/10.3390/agriculture12020281

Duque-Buitrago, L. F., Solórzano-Lugo, I. E., González-Vázquez, M., Jiménez-Martínez, C., Hernández-Aguirre, M. A., Osorio-Díaz, P., Calderón-Domínguez, G., Loera-Castañeda, V., Mora-Escobedo, R. 2024. Health-Related Composition and Bioactivity of an *Agave* Sap/Prickly Pear Juice Beverage. Molecules, 29, 2742. https://doi.org/10.3390/molecules29122742

El Kossori, R. L., Villaume, C., El Boustani, E., Sauvaire, Y., Méjean, L. 1998. Composition of pulp, skin and seeds of prickly pears fruit (*Opuntia ficus indica* sp.). Plant Foods Hum Nutr. 52(3):263-70. doi: 10.1023/a:1008000232406.

Eroglu, E. C., Arslan, R., Güleç, A., Aksay, S. 2021. Determination of physical and phytochemical properties of prickly pear (*Opuntia ficus-indica* L.). Journal of Food Processing and Preservation, 46, e15990. https://doi.org/10.1111/jfpp.15990.

Eseberri, I., Gómez-Maqueo, A., Trepiana, J., Gómez-López, I., Carina Proença, C., Pilar Cano, M., Portillo, M. 2024. In vitro screening and lipid-lowering effect of prickly pear (*Opuntia ficus-indica* L. Mill.) fruit extracts in 3T3-L1 pre-adipocytes and mature adipocytes. Plant Foods for Human Nutrition, 79:143–150. https://doi.org/10.1007/s11130-023-01137-8.

Esteem research. 2023. Functional Food and Nutraceuticals Market Size 2023 - 2030 Global Industrial Analysis, Key Geographical Regions, Market Share, Top Key Players, Produc. Accessed: Jun. 26, 2024. [Online]. Available: https://www.linkedin.com/pulse/functional-food-nutraceuticals-market-size-2023-2030-5nfrc#:~:text=Increasing%20awareness%20of%20the%20link,the%20demand%20for%20these%20products.

Es-sbata, I., Castro, R., Zouhair, R., Durán-Guerrero, E. 2023. Effect of the type of acetic fermentation process on the chemical composition of prickly pear vinegar (*Opuntia ficus-indica*). J Sci Food Agric, 103:264-272. https://doi.org/10.1002/jsfa.12138.

Fernández, M. R., Mondragón, C., Gutiérrez, F., Sáenz, L. A., Zegbe, J. A., Méndez, S., Martínez, J. 2000. Principales cultivares mexicanos de nopal tunero. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Centro de Investigación Regional del Centro, Campo Experimental Norte de Guanajuato. San Luis de la Paz, Guanajuato, México.

Feugang, J. M. 2006. Nutritional and medicinal use of cactus pear (*Opuntia* spp.) cladodes and fruits. Frontiers in Biosci. 11(1): 2574. doi: 10.2741/1992.

Fouad O. F., Abou-Zaid, Fatma A., Ahmed, Abd El-Hameed A., Ibraheem. 2022. Using of prickly pear (*Opuntia* Spp.) fruit juice and peels in cookies production. Alexandria Science Exchange Journal, 43 (2):239-248. 10.21608/asejaiqjsae.2022.239236.

Gannuscio, R., Vastolo, A., Maniaci, G., Lucia, C., Calabrò, S., Todaro, M., Cutrignelli, M. I. 2024. Improve nutritive value of silage based on prickly pear peel by-products. Italian Journal of Animal Science, 23(1), 492–503. https://doi.org/10.1080/1828051X.2024.2323629.

Ha, Q. T. T., Nguyen, K. K., Le, A. N., Vu, H. T., Nguyen, T. N. 2024. *Opuntia ficus-indica* (L.): An Overview of the Recent Application and Opportunities in Food. Tropical Journal of Natural Product Research (TJNPR), 8(1):5734–5745. http://www.doi.org/10.26538/tjnpr/v8i1.3.

Hahn-Schlam, F., Valle-Guadarrama, S., Jenkins, T. 2019. Robotic cactus pear cryocauterization increases storage life. Postharvest Biol. Technol. 147, 132–138.

Hallim, A. M., Rabie, A., El-Shewey, M. A., Abdel-Ghany, A. S. 2019. Evaluation of physico-chemical properties and antioxidant activity of stirred yoghurt fortified with pomegranate and cactus pear juices. Zagazig J. Agric. Res., 46:6A.

Inglese, P., Mondragón-Jacobo, C., Nefzaoui, A., Sáenz, C. 2017. Food and agriculture organization of the United Nations, and international center for agricultural research in the dry areas, Crop ecology, cultivation and uses of cactus pear. Rome, Italy: FAO. Accessed: Apr. 21, 2023. [Online]. Available: http://www.fao.org/3/a-i7628e.pdf

Karabagias, V. K., Karabagias, I. K., Gatzias, I., Riganakos, K. A. 2019. Characterization of prickly pear juice by means of shelf life, sensory notes, physicochemical parameters and bio-functional properties. J Food Sci Technol 56, 3646–3659. https://doi.org/10.1007/s13197-019-03797-4.

Matias, A. G., Araujo, G. G., Campos, F. S., Moraes, S. A., Gois, G. C., Silva, T. S., Emerenciano Neto, J. V., Voltolini, T. V. 2020. Fermentation profile and nutritional quality of silages composed of cactus pear and maniçoba for goat feeding. J Agric Sci. 158(4):304–312. doi: 10.1017/S0021859620000581.

Martins, M., Ribeiro, M. H., Almeida, C. M. 2023a. New foods with history: nutritional and toxic profile of prickly pear. J Food Meas Charact., 17(1): 956–972. doi: 10.1007/s11694-022-01680-z.

Martins, M., Ribeiro, M. H., Almeida, C. M. 2023b. Physicochemical, nutritional, and medicinal properties of *Opuntia ficus-indica* (L.) Mill. and its main agro-industrial use: a review. Plants. 2023; 12(7):1512. doi: 10.3390/plants12071512.

Maurya, A. P., Chauhan, J., Yadav, D. K., Gangwar, R., Maurya, V. K. 2021. Nutraceuticals and their impact on human health. In Preparation of Phytopharmaceuticals for the Management of Disorders (pp. 229-254). Academic Press. https://doi.org/10.1016/B978-0-12-820284-5.00011-3.

Melgar, B., Dias, M. I., Ciric, A., Sokovic, M., Garcia-Castello, E. M., Rodriguez-Lopez, A. D., Barros, L., Ferreira, I. 2017. By-product recovery of *Opuntia* spp. peels: betalainic and phenolic profiles and bioactive properties. Industr Crops Prod. 107:353–359. doi: 10.1016/j.indcrop.2017.06.011.

Morshedy, S. A., Abdal-Mohsen, A. E., Basyony, M. M., Almeer, R., Abdel-Daim, M. M., El-Gindy, Y. M. 2020. Effect of prickly pear cactus peel supplementation on milk production, nutrient digestibility and rumen fermentation of sheep and the maternal effects on growth and physiological performance of suckling offspring. Animals. 10(9):1476. doi: 10.3390/ani10091476.

Muñoz E., E. 2024. La Feria de la Tuna en San Martín de las Pirámides: espacio de tradición y comercialización. Narrativas antropológicas 5(9):55-68.

Muñoz de Chávez, M., Chávez, A., Valles, V., Roldán, J. A. 1995. The nopal: a plant of manifold qualities. World Rev Nutr Diet. 77:109-34. doi: 10.1159/000424468.

Nesreen, M., El-Said, Ali. 2013. Utilization of the wholly Prickly pear fruit juice [*Opuntia ficus-indica* (L.) *Mill*]: Peels source of functional components and its shelf-life storage. Egyptation Journal of Nutrition, 28(1): 89-120.

Ortega-Hernández, E., Welti-Chanes, J., Jacobo-Velázquez, D. A. 2018. Effects of UVB Light, Wounding Stress, and Storage Time on the Accumulation of Betalains, Phenolic Compounds, and Ascorbic Acid in Red Prickly Pear (*Opuntia ficus-indica* cv. Rojo Vigor). Food Bioprocess Technol. 11, 2265–2274.

Özcan, M. M., Alkaltham, M. S., Matthaus, B., Şimşek, S., Salamatullah, A. M., Hayat, K. M., Ahmed. I. A. 2022. Changes in sugar contents, amino acid, sterol and tocopherol compositions of prickly pear fruit and seed oils. Indian Journal of Traditional Knowledge, 21(3):646-652.

Palmeri, R., Parafati, L., Arena, E., Grassenio, E., Restuccia, C., Fallico, B. 2020. Antioxidant and antimicrobial properties of semi-processed frozen prickly pear juice as affected by cultivar and harvest time. Foods, 9, 235; doi:10.3390/foods9020235.

Pinedo-Espinoza, J. M., Aguirre-Mancilla, C. L, Jiménez-Alvarado, R., Raya-Pérez, J. C., Iturriaga, G., Ramírez-Pimentel, J. G., Hernández-Fuentes, A. D. 2017. Bioactive compounds and antioxidant activity evolution during the ripening process of 12 *Opuntia spp*. Fruit accessions. Emirates Journal of Food and Agriculture. 29(2): 138-148 doi: 10.9755/ejfa.2016-09-1324.

Prieto, C., Sáenz, C., Silva, P., Loyola, E. 2009. Balsamic type vinegar from colored ecotypes of cactus pear (*Opuntia ficus-indica*). Acta Hortic 811:123–126.

Rahimi, P., Abedimanesh, S., Mesbah-Namin, S. A., Ostadrahimi, A. 2018. Betalains, the nature-inspired pigments, in health and diseases. Crit. Rev. Food Sci. Nutr., 1–30.

Regalado-Rentería, E., Aguirre-Rivera, J. R., González-Chávez, M. M., Sánchez-Sánchez, R., Martínez-Gutiérrez, F., Juárez-Flores, B. I. 2020. Assessment of extraction methods and biological value of seed oil from eight variants of prickly pear fruit (*Opuntia* spp.). Waste Biomass Valoriz. 11:1181–1189.

Robles-Contreras, F., Macías-Duarte, R., Grijalva-Contreras, R. L. 2008. Tecnología de producción de nopal verdura para el noroeste de Sonora. Centro de Investigación Regional del noroeste. Campo experimental Costa de Hermosillo (INIFAP). Folleto técnico, 46 págs.

Sáenz, C., Berger, H., Rodríguez-Félix, A., Galletti, L., Corrales-García, J., Sepúlveda, E., Varnero, M. T., García de Cortázar, V., Cuevas-García, R., Arias, E., Mondragón, C., Higuera, I., Rosell, C. 2013. Agro-industrial utilization of cactus pear. Rome, Italy: FAO.

SAGARPA, U. 2015. Estudio de factibilidad para el establecimiento de cultivo de nopal (*Opuntia*) en tierras ociosas en los estados de Aguascalientes, San Luis Potosí, Guanajuato y Zacatecas con fines alimenticios, energéticos y ambientales. Sagarpa Universidad Autónoma de Zacatecas.

Scalone, D., Stuto, A., Licciardello, F., Muratore, G., Todaro, A., Spagna, G. 2012. Strategies for the extension of the shelf life of ready to eat prickly pear fruits. Italian Journal of Food Science / Rivista Italiana di Scienza degli Alimenti. 24(4): p174.

SIAP. 2024. Sistema de Información Agroalimentaria y Pesquera. Anuario Estadístico de la Producción Agrícola, Cierre de la producción agrícola. Accessed: Jun. 28, 2024. [Online]. Available: https://nube.siap.gob.mx/cierreagricola/.

Siddique, F., Ghazala A., Parveen S., Ali Z., Shabbir A., Mubeen K. 2024. Innovative food products - nutraceuticals and functional foods review-based book chapter consumer trends and nutrified food. In book: innovative food products - Nutraceuticals and functional foods. Publisher: Scientific Knowledge Publisher (SciKnowPub), USA. DOI: 10.5281/zenodo.11189506.

Stavi, I. 2022. Ecosystem Services Related with *Opuntia ficus-indica* (Prickly Pear Cactus): A Review of Challenges and Opportunities. Agroecol. Sustain. Food Syst., 46, 815–841. https://doi.org/10.1080/21683565.2022.2076185.

Todaro, M., Alabiso, M., Di Grigoli, A., Scatassa, M. L., Cardamone, C., Mancuso, I., Mazza, F., Bonanno, A. 2020. Prickly pear by-product in the feeding of livestock ruminants: preliminary investigation. Animals. 10(6):949. doi: 10.3390/ani10060949.

Vastolo, A., Calabrò, S., Cutrignelli, M. I., Raso, G., Todaro, M. 2020. Silage of prickly pears (*Opuntia* spp.) juice by-products. Animals. 10(9):1716. doi: 10.3390/ani10091716.

Yahia, E. M. 2012. Prickly Pear Fruit and Cladodes. Chapt. 13, in: Rees, D., Farrell, G., Orchard, J. Crop Post-Harvest: Science and Technology (Perishables). 264–285. doi:10.1002/9781444354652.ch13.

Zegbe, J. A., Serna-Pérez, A., Mena-Covarrubias, J. 2015. Irrigation enhances postharvest performance of "Cristalina" cactus pear fruit. Acta Hortic. 1067, 417–422.

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