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Prickly Pear (*Opuntia spp.*) as a Natural Source of Bioactive Compounds for Functional Food Fortification: A Comprehensive Chemical, Technological, and Sensory Study

Nasser I. E. Abo El-Naga[1], Neveen F. M. Agamy[2], Kamala S. K. El Nagar[1] and Mina S. R. Abd-Ellahot[3*]

[1]*Home Economics Department Faculty of Agriculture El-Shatby, 21545, Alexandria University, Alexandria, Egypt.*

[2] *Institute of Public Health, Alexandria University, Alexandria, Egypt.*

[3]*Food Science and Technology Department, Faculty of Agriculture El-Shatby, 21545, Alexandria University, Alexandria, Egypt.*

FORTIFYING meals with functional fibers is an increasing global trend, attributed to their benefits in developing health-promoting food products and their potential role in preventing health issues such as obesity, diabetes mellitus, and cardiovascular diseases. Therefore, this study aims to assess the potential utilization of prickly pear (*Opuntia spp*.) as a natural source of therapeutic nutraceuticals for functional food applications. The prickly pear pulp and its by-products including peels and seeds were analyzed to determine their chemical composition, mineral content, and nutritional attributes as vitamins, polyphenols and pigments, and their potential application in the formulation of functional food products. Chemical analysis revealed variations in the chemical composition of various parts of the prickly pear. The pulp showed the highest levels of carbohydrates (93.38%) and fibers (68.20%), whereas the seeds were richest in protein (10.66%) and fats (15.40%). The peels had the highest concentrations of beta-carotene (1.17 mg/100g) and antioxidants (88.23%). The study evaluated the sensory properties of processed foods fortified with prickly pear pulp, peels, and seeds. Results showed differences in consumer acceptance, color, odor, and texture depending on the percentage of the ingredient incorporated. Cakes and Cerelac reached the highest acceptance scores when fortified with 30% prickly pear peels, while biscuits and noodles were most favored with a 20% addition. Sensory assessments of cakes, biscuits, and noodles cerelac, jam, and syrup showed significant differences in taste, flavor, and general acceptance.

Keywords: Prickly pear, Antioxidants, Peels, Pulp, Seeds, Prickly pear peels flour Functional foods.

Introduction

Prickly pear (*Opuntia ficus-indica*) is a crop of considerable agronomic and nutritional value, widely cultivated in tropical and subtropical regions, including Mexico, South Africa, and Mediterranean countries such as Egypt. It is well adapted in semi-arid and arid environments. Traditionally, it has been utilized in the treatment and management of various health conditions, including diabetes, arteriosclerosis, asthma, burns, and gastritis (Bouazizi et al., 2020). In the food processing industry, prickly pear (*Opuntia ficus-indica*) peel represents a significant agro-industrial by-product, constituting approximately 48% of the total fruit weight. Its accumulation presents both environmental and economic challenges due to high management costs. Nevertheless, the effective utilization of this by-product could not only mitigate waste management challenges but also serve as a promising source of high-value bioactive compounds.

*Corresponding Author: E-mail: mina.ragheb@alexu.edu.eg
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Prickly pear seeds represent an underutilized resource with considerable nutritional potential. They are rich in essential minerals (Fe, Cu, Zn, and Se) and contain substantial amounts of unsaturated fatty acids, predominantly linoleic acid, followed by oleic and palmitic acids. The seed powder serves as an important source of natural fiber, protein, oil, vitamins, phenolic compounds, and antioxidants, and was found to be free of fungal metabolites such as aflatoxin and ochratoxin (Elsaid et al., 2020). Recent studies have shown that prickly pear contains a variety of bioactive compounds, including flavonoids, phenolics, ascorbic acid, betalains, and essential minerals (Sabtain et al., 2021; Chiteva and Wairagu, 2013).

The objective of this research is to investigate the chemical composition of prickly pear and evaluate its potential applications in the food industry through fortification for the development of functional food products. Further research is needed to design new food systems that consider both the technological and physiological functionality of dietary fiber along with micronutrients. The growing recognition of the health benefits and functional properties of fiber has led to the development of high-fiber products. Consequently, there is increasing interest in exploring alternative sources of dietary fiber, particularly from underutilized by-products, which offer promising opportunities for the food industry.

Materials and Methods

Materials

During the summer, ripe *Opuntia ficus-indica* (prickly pear) fruit had been obtained from a nearby farm in Alexandria (Egypt). Wheat flour (72 % extraction ratio), sucrose (commercial grade), fat (shortening), fresh whole eggs, baking powder (sodium bicarbonate and cream tartart), salt, cow milk, sunflower oil and vanilla (pure vanillin) were purchased from Alexandria local markets, Egypt. All chemicals used in this study were analytical grade and were purchased from El-Gamhouria Co. for Chemical and Medical Requisition, in Alexandria, Egypt.

Methods

Preparation of prickly pear samples (juice, seeds and peels)

Prickly pear fruits (PPJs) were washed peeled, juiced, and the seeds were separated. The juice was stored frozen at −4 °C until use, following the procedure described by Madrigal-Santillán et al. (2013). Prickly pear seeds (PPSs) were separated, washed, dried, cracked, and sieved to recover their pericarps, as reported by Nassar (2008). Prickly pear peels (PPPs) were washed, cut, dried, ground, and standardized into flour. Moisture content was determined, and the resulting flour was vacuum-packed and stored at −18 °C for further analysis, (Parafati et al., 2020).

Chemical composition

Proximate composition of the prickly pear samples including moisture, crude protein, crude fat, crude fiber and ash was determined according to the official AOAC (2012) procedures while the nitrogen-free extract (NFE) was obtained by difference. The minerals as calcium (Ca), potassium (K), sodium (Na), iron (Fe), and zinc (Zn) were quantified from the ash solution using an Atomic Absorption Spectrophotometer (300VA-50-60 Hz-100- 240V) UK according to AOAC method No.968.08, 2005.

Bioactive constituents

Dietary fiber

The dietary fiber fractions, including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), were determined according to Goering and Van Soest (1970) methods. The contents of hemicellulose and cellulose were calculated using the following relationships:

% Hemicelluloses = %NDF - %ADF

% Cellulose= %ADF - %ADL

Total phenolic content

The phenolic contents were extracted with methanol (containing 0.1% HCl) as a solvent. 10 grams of PPJ, PPSs, and PPPs were individually blended with the solvent at a ratio 1: 20 (w/v) and extracted twice at room temperature. The combined extracts were stored at −18 °C until analysis. Total phenolic content was measured at 750 nm with a UV–Vis spectrophotometer (Optizin, Thermo Electron Corporation, Korea) according to the AOAC (2012), applying the Folin–Ciocalteu reagent and tannic acid as the calibration standard.

Antioxidant capacity (AC)

The antioxidant capacity of the extracts was evaluated using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay, DPPH assay according to the procedure of Baek et al. (2008)

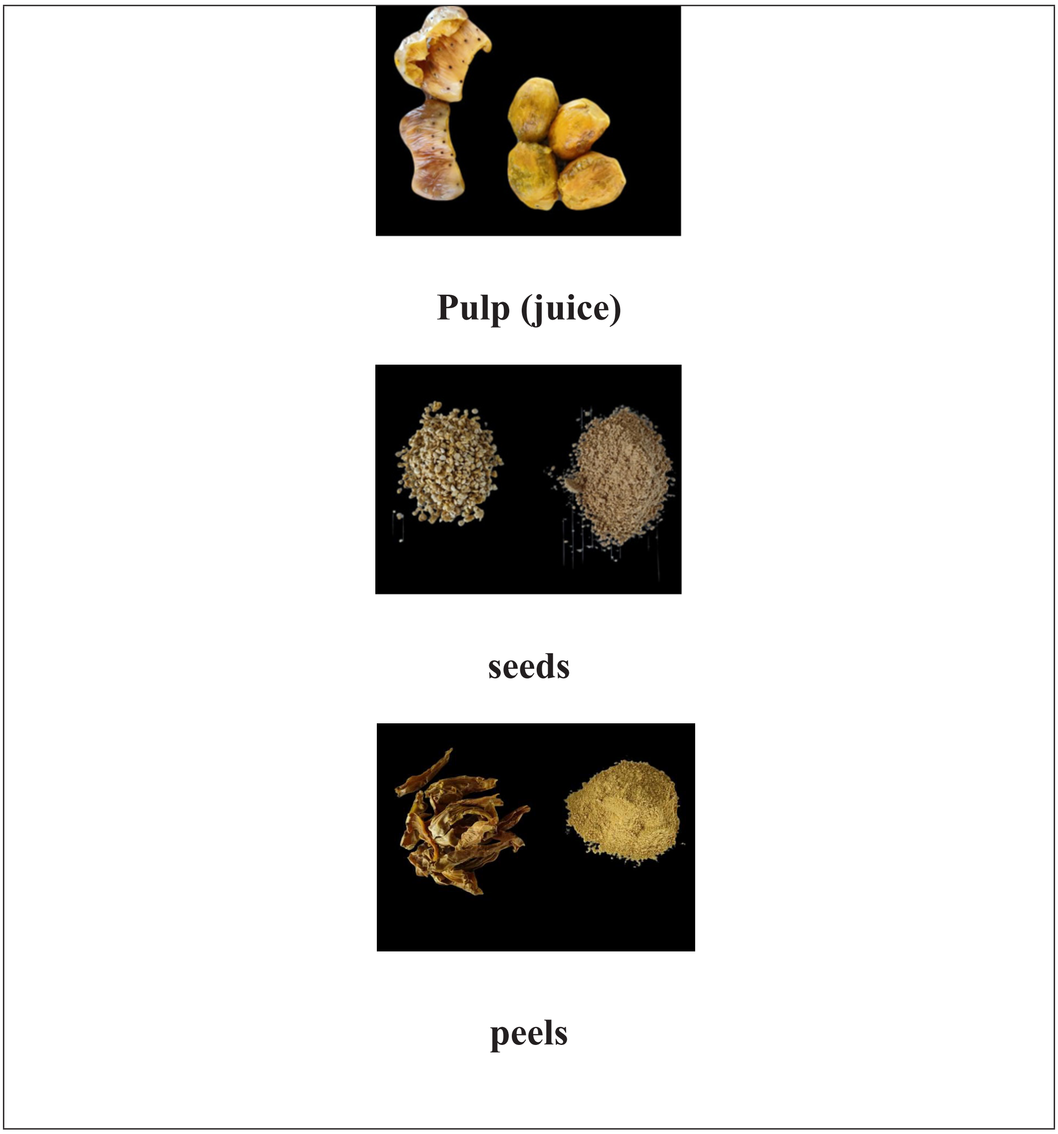

Fig . 1. The pulp, seeds, and peels.

Vitamin contents

Vitamin C content was determined through titration with 2, 6-dichlorophenol indophenol dye, in accordance with AOAC (2012). The determination of vitamin E was conducted using a high-performance liquid chromatography (HPLC) System Controller (SCL-6A) equipped with a Shimadzu CTO 6-A column oven and SPD-6AV detector, under the operation of a high-pressure solvent delivery unit (LC-20AD), according to the AOAC (2012). A 20 µL sample was injected and eluted at a flow rate of 2 mL/min for 15 min at 20 °C. Vitamin E was identified and quantified by comparing its retention time with that of previously injected standards.

Determination of phytopigments

Total carotenoids were extracted with 95% acetone (1:10) mixed and calorimetrically measured at a wavelength of 460 nm, using a spectrophotometer (Spectronic model.20, Milton Roy Co., USA), and expressed as µg/g according to Britton et al. (2004). Anthocyanin content was extracted, measured by Photoelectric Colorimeter at 535 nm, and expressed as µg/g following the procedure established by Fuleki and Francis (1968).

Technological methods

Certain products were prepared as an approach to investigate the possible application of prickly pear in the functional food industry.

Preparation of cake

Cake formulations were prepared as described by Nor-Aini et al. (1992), The ingredients used in the preparation of the cake fortified with prickly pear pulp and peel are presented in Table 1

Preparation of ammonia biscuits

For the preparation of biscuit dough, the method described by Mousa (2019) was followed. Table 2 shows the ingredients used in the preparation of ammonia biscuits.

Preparation of instant noodles

The noodle formulation was prepared according to the method described by Taneya et al. (2014), with a replacement of 20% of wheat flour by dried prickly pear peel flour (PPPF) and prickly pear seed flour (PPSF), as shown in Table 3.

Cerelac fortification

Wheat cereal was purchased from a local pharmacy in Alexandria. Prickly pear peel flour (PPPF) was incorporated at substitution levels of 20% and 30%. The product was prepared by adding 320 mL of distilled water, following the Cerelac preparation instructions provided on the package (Table 4).

Fresh pure juice preparation

One kilogram of prickly pear was manually peeled with a knife, the pulp was squeezed, and the seeds were discarded without the addition of any other ingredients. The juice was then stored at –4 °C until subjected to sensory evaluation (Tressler and Joslyn, 1954).

Concentrated juice (Syrup)

Sugar was added to the fruit juice to prepare a fruit syrup, which was then concentrated by heating to achieve a final sugar concentration of 65%, measured using a refractometer. The natural sugar content of the fruit must be considered when calculating the amount of sugar to be added. The volume of water added to reconstitute fruit juice from the syrup depends on consumer taste and desired sweetness. The amount of water required to achieve a final juice sugar content of 12–14% can be calculated using the Pearson Square method (Tressler and Joslyn, 1954).

TABLE 1. Ingredients of shortened cake prepared with prickly pear juice (PPJ) and prickly pear peels Flour (PPPF).

Ingredients (g)	Control	100 % PPJ	20 % PPP	30 % PPP
Wheat flour (72% extraction)	150	150	120	105
Sugar	100	100	100	100
PPJ	-	50	-	-
PPP	-	-	30	45
Fat	50	50	50	50
Cow Milk	50	-	50	50
Whole egg	50	50	50	50
Baking powder	4	4	4	4

TABLE 2. Ingredients of ammonia biscuits prepared with prickly pear juice (PPJ) and prickly pear peels Flour (PPPF).

Ingredients (g)	Control	100 % PPJ	20 % PPP	30 % PPP
Wheat flour (72% extraction)	80	80	64	56
Sugar	35	35	35	35
PPJ	-	17.6	-	-
PPPF	-	-	16	24
sunflower oil	20	20	20	20
Water	17.6	-	17.6	17.6
Salt	1	1	1	1
Baking powder	0.8	0.8	0.8	0.8
Ammonia	0.4	0.4	0.4	0.4

TABLE 3. Ingredients of instant noodles prepared with dried prickly pear peels flour (PPPF) and prickly pear seeds flour (PPSF).

Ingredients (g)	Control	20 % PPS	20 % PPP
Wheat flour (72% extraction)	100	80	80
PPS	-	20	-
PPPF	-	-	20
Oil	5	5	5
Water	31	31	31
Salt	1	1	1
Baking powder	1	1	1
Ginger juice	1	1	1
Citric acid	0.1	0.1	0.1
Egg	10	10	10
Cumin powder	0.5	0.5	0.5
Garlic powder	0.1	0.1	0.1
Onion powder	0.5	0.5	0.5

TABLE 4. Ingredients of Cerelac fortified with dried prickly pear peel flour (PPPF).

Ingredients (g)	Control	20% PPPF	30 % PPPF
Wheat cerelac	50	40	30
PPPF	-	10	20
Water	320	320	320

Preparation for jam

The jam product was prepared according to Bekele et al. (2020). Prickly pear jam was made by mixing 500 g of prickly pear concentrate juice with 400 g of sugar, 10 g of pectin, and 1 g of citric acid. First, half of the sugar and the citric acid were added to the juice and boiled until reaching a Brix value of 50˚. The remaining sugar was then added, and boiling continued until reaching Brix 64˚. Pectin was added afterwards, and boiling was continued until a final Brix of 70˚ was achieved. The jam was then filled into sterilized glass bottles while hot, allowed to cool and settle, and finally stored for subsequent sensory evaluation.

Sensory evaluation

Organoleptic properties of products were evaluated by 20 panelists trained of home economy, Faculty of Agriculture, Alexandria University, according to Ranganna (2000).

Statistical analysis

Data were subjected to analysis for statistical significance at P≤ 0.001 using the statistical package for social sciences software (SPSS, version 22, 2018), in accordance with the literature (Gomez and Gomez, 1984).

Results and Discussion

Analysis of prickly pear parts (pulp, peels, and seeds) revealed significant compositional differences. The data presented in Table 5 show that the moisture content of the samples was 87.64%, 11.45%, and 6.35% for pulp, peels, and seeds, respectively. Our results for the pulp were in agreement with those reported by Sabtain et al. (2021) and Chiteva & Wairagu (2013), who found the pulp moisture content of 87.07%. The moisture content of peels was higher than the values reported by El-Beltagi et al. (2023); Albergamo et al. (2022); El-Hassan et al. (2022) and Parafati et al. (2020), which were 6.58%, 10.12%, 8.27%, and 8.17%, respectively, but lower than that reported by El-Said et al. (2011) (18.50%). The moisture content of seeds was within the range reported by AbdelFattah et al. (2020) (6.50%) but higher than values reported by Albergamo et al. (2022) (3.39%), Ali et al. (2020) (4.78%), and Reda & Atsbha (2019) (4.17%). Our results were, however, lower than that reported by Nassar (2008) (9.03%). These differences in moisture content may be attributed to variations in cultivation regions.

The dried prickly pear fruit parts contained relatively low ash content. As shown in Table 5, ash contents were 2.15%, 12.65%, and 1.85% for pulp, peels, and seeds, respectively. The ash content of prickly pear peels was consistent with the values reported by Bellache et al. (2022) and Kossori et al. (1998), who reported 12.10% for peel by-products. The ash content of seeds was similar to that recorded by Albergamo et al. (2022) (1.79%). The pulp ash content was comparable to that reported by Asma et al. (2017) (2.45%) but lower than values reported by Sabtain et al. (2021), Chiteva and Wairagu (2013), and Kossori et al. (1998), which were 4.03%, 4.03%, and 8.50%, respectively. These variations in ash content of *Opuntia ficus-indica* may be due to differences in fertilization, soil composition, and climatic conditions (Chinedu et al., 2017).

On a dry matter basis, the highest crude protein content was found in the seeds (10.66%), followed by the peels (7.71%) and the pulp (4.42%), indicating that prickly pear is a good source of dietary protein (Table 5). The crude protein content of prickly pear seeds was consistent with the value reported by AbdelFattah et al. (2020) (10.70%) but lower than those reported by Nassar (2008) and Kossori (1998), which were 13.62% and 11.8%, respectively. Conversely, it was higher than the values recorded by Kolniak-Ostek et al. (2020) and Salim et al. (2009), which were 9.45% and 4.48%, respectively.

The protein content in the peels was lower than that reported by Kossori (1998) (8.3% DM) but higher than the values reported by Parafati et al. (2020), Abdel-Razek et al. (2019), and Salim et al. (2009), which were 3.58%, 4.5%, and 1.45%, respectively. For the pulp, our results were similar to those reported by Mondragón-Jacobo (2001), who found a protein content of 4%, but lower than the values found by Elshehy et al. (2020) and Kossori (1998), which were 5.6% and 5.1%, respectively. However, our recorded value was higher than those reported by Cota-Sánchez (2016), Chiteva and Wairagu (2013), and Salim et al. (2009), who found protein contents of >1%, 1.45%, and 1.03%, respectively. These differences in protein content may be attributed to regional variations.

Table 5 showed that the crude fat content of dried prickly pear pulp was very low (0.054%). This result was lower than the values reported by Albergamo et al. (2022), Bellache et al. (2022), Sabtain et al. (2021), Chiteva and Wairagu (2013), and Kossori et al. (1998), which were 1.12%, 0.7–1%, 0.40%, 0.4%, and 0.97%, respectively. However, the crude fat content in the pulp was close to that reported by Kamble et al. (2017) and Feugang et al. (2006), which were 0.09% and 0.07%, respectively.

Regarding the peels, Albergamo et al. (2022), El-Said et al. (2011), and Kossori et al. (1998) reported total fat contents of 5.04%, 6.99%, and 2.43%, respectively, which are lower than our observed value of 11.41%. The seeds had the highest crude fat content, reaching 15.37%. This value is higher than those reported by Albergamo et al. (2022), Bellache et al. (2022), and Kossori et al. (1998), who reported crude fat contents of 9.65%, 6.77%, and 6.77%, respectively. Variations in fat content have been shown to depend on seasonal variations, species, physiological status, and the stage of fruit maturity.

From the data in Table 5, it was observed that prickly pear pulp had the highest carbohydrate content (93.38%), followed by seeds (72.08%) and peels (68.31%). These values are influenced by cultivar, season, and plant parts. The obtained results were very close to those reported by Sabtain et al. (2021) and Chiteva and Wairagu (2013), who found total carbohydrates in the pulp to be 92.57% in both studies. The values were higher than those reported by Albergamo et al. (2022) (74.34%) and Inglese et al. (2017) (50–75%).

For the peels, our results were close to those reported by Albergamo et al. (2022) (65.23%) but lower than the value reported by Parafati et al. (2020) (73.41%). El-Beltagi et al. (2023), El-Hassan et al. (2022), and Manzur-Valdespino et al. (2022) reported carbohydrate contents of 49.93%, 41.01%, and 27.60%, respectively. For the seeds, Albergamo et al. (2022), AbdelFattah et al. (2020), Ali et al. (2020), Reda & Atsbha (2019), El-Safy et al. (2012), and Nassar (2008) reported carbohydrate contents lower than the values found in the present study, which were 49.75, 28.22, 23.26, 55.47, 13.45, and 51.11%, respectively.

Crude and dietary fibers

The content of crude fiber compounds is an important factor in evaluating the quality of by-products and plays a significant role in their physical properties as well as in various physiological processes. Dietary fiber contributes to the prevention of several illnesses, including constipation, hypertension, hyperlipidemia, atherosclerosis, heart diseases, liver cirrhosis, diabetes, cancer, and others (Hayyat et al., 2024; Mathers, 2023; Champ et al., 2003).

TABLE 5. Proximate chemical composition of (Opuntia ficus-indica) prickly pear pulp, peels, and seeds on dry weight basis.

Material	Moisture (%)	Ash	Protein	Fat	Carb
Pulp	87.64[a]	2.15[b]	4.42[c]	0.05[c]	93.38[a]
Peels	11.45[b]	12.65[a]	7.68[b]	11.36[b]	68.31[c]
Seeds	6.35[c]	1.85[b]	10.66[a]	15.40[a]	72.08[b]
SE±	0.05	0.05	0.12	0.08	0.24

a, b and c: Means having different superscripts within each column are significantly different (p <0.001).
SE: standard error

TABLE 6. Crude and dietary fibers content of prickly pear pulp, peels and seeds have been determined on dry weight basis.

	Content / Dry matter %					
Material	**Crude fibers**	**NDF**	**ADF**	**ADL(Lignin)**	**Hemi cellulose**	**Cellulose**
Pulp	68.16[a]	7.18[c]	7.06[c]	4.88[b]	0.13[c]	2.17[c]
Peels	35.48[c]	12.65[b]	9.39[b]	3.00[c]	3.28[b]	6.40[b]
Seeds	51.53[b]	69.66[a]	63.42[a]	24.42[a]	6.24[a]	39.00[a]
SE±	0.05	0.09	0.02	0.01	0.01	0.01

a, b and c: Means having different superscripts within each column are significantly different (p <0.001).
SE: standard error

The obtained results indicated that the crude fiber content varied significantly among different parts of the prickly pear ($p < 0.05$). The highest fiber contents were observed in the pulp (68.14%) and seeds (51.49%) (Table 6), confirming that prickly pear is a valuable source of crude fiber. The crude fiber content of the pulp recorded in this study was higher than those reported by Albergamo et al. (2022), Bellache et al. (2022), Sabtain et al. (2021), Kamble et al. (2017), Chiteva & Wairagu (2013), Feugang et al. (2006), and Kossori et al. (1998), who reported values of 4.06%, 20.50%, 1.37%, 0.23%, 1.37%, 0.02–3.15%, and 20.50%, respectively. Similarly, the crude fiber content of the peels was higher than those reported by El-Beltagi et al. (2023), Albergamo et al. (2022), and El-Said et al. (2011), who recorded values of 25.79%, 12.54%, and 4.88%, respectively. However, it was lower than the values reported by Bellache et al. (2022), Manzur-Valdespino et al. (2022), and Kossori et al. (1998), who all recorded 40.8%.

On the other hand, the crude fiber content of the seeds in this study (51.53%) was very close to that reported by Ali et al. (2020) (50.81%). It was lower than the values reported by Bellache et al. (2022) and Kossori et al. (1998) (54.2%) but higher than those reported by Albergamo et al. (2022), AbdelFattah et al. (2020), Reda & Atsbha (2019), El-Safy et al. (2012), and Nassar (2008), who reported 16.28, 46.31, 18.23, 49.61, and 9.23%, respectively. Considering its high carbohydrate, fiber, and protein content, along with its low-fat content, *Opuntia ficus-indica* (prickly pear) can be regarded as a food with considerable nutraceutical potential.

Mineral content

Minerals are essential for maintaining human health and supporting vital bodily functions, including building strong bones and teeth (calcium, phosphorus), oxygen transport via hemoglobin (iron), activating enzymes and supporting biochemical reactions (zinc, magnesium), and ensuring proper nerve and muscle function (potassium, magnesium). A deficiency in these minerals can lead to serious health problems, while a balanced diet is necessary to ensure adequate intake (Lanham-New et al., 2021; Ross et al., 2020; Prasad, 2017; Mahan and Raymond, 2017). The data indicated that prickly pear is a good source of the analyzed minerals, as shown in Table 7. Significant differences ($p < 0.05$) were observed in the mineral composition of prickly pear parts. Potassium was the predominant mineral in the pulp (603.81 mg/100 g DW) and seeds (419.00 mg/100 g DW), while calcium was highest in the peels (183.66 mg/100 g DW). Seeds exhibited the highest iron content (53.55 mg/100 g DW), followed by peels (41.78 mg/100 g DW) and pulp (36.40 mg/100 g DW).

Bellache et al. (2022) and Kossori et al. (1998) indicated that the prickly pear pulp contained K (559 mg), followed by Ca (163 mg) and Fe (16.5 mg), whereas Mn (6.99 mg) and Zn (1.55 mg) were present in smaller amounts. Similarly, Albergamo et al. (2022) reported K (187.05 mg), Zn (5.09 mg), Fe (2.39 mg), and Mn (0.78 mg). Díaz et al. (2017) also noted that the potassium content of the pulp was 2403 mg, calcium 627 mg, manganese 13.8 mg, and iron 8.6 mg, while zinc was not detected. Sabtain et al. (2021) and Kamble et al. (2017) reported K (161 mg), Ca (27.6 mg), and Fe (1.5 mg) in the pulp, but did not detect Zn or Mn. On the other hand, Chiteva & Wairagu (2013) reported Ca as the major element in the pulp (316.5 mg), followed by K (108.8 mg), Mn (37.8 mg), Fe (25.9 mg), and Zn (12.6 mg).

For the peels, El-Beltagi et al. (2023), El-Hassan et al. (2022), Manzur-Valdespino et al. (2022), and El-Said et al. (2011) reported calcium as the predominant mineral, albeit in varying proportions, whereas Albergamo et al. (2022), Bellache et al. (2022), and Kossori et al. (1998) identified potassium as the most abundant. El-Beltagi et al. (2023) noted Ca (929 mg), K (304 mg), Fe (117.5 mg), Zn (100.5 mg), and Mn (99.5 mg). El-Hassan et al. (2022) reported Ca (922 mg), K (312 mg), and Fe (132 mg). Manzur-Valdespino et al. (2022) recorded very low values: Ca (0.951 mg), K (0.320 mg), Fe (0.129 mg), Zn and Mn (0.90 mg each). El-Said et al. (2011) stated that Ca was 951 mg, K 320 mg, Fe 129 mg, Mn 90.80 mg, and Zn 90 mg. According to Albergamo et al. (2022), K was 1820.83 mg, followed by Mn (46.86 mg), Zn (24.96 mg), and Fe (15.27 mg). Conversely, Miranda et al. (2018) did not detect Ca or Fe. Bellache et al. (2022) and Kossori et al. (1998) indicated that potassium was the major mineral in the peels (3430 mg/100 g), followed by calcium (2090 mg/100 g), manganese (72.9 mg/100 g), Fe (8.3 mg/100 g), and Zn (1.70 mg/100 g).

For the seeds, Bellache et al. (2022) and Kossori et al. (1998) reported K (122–275 mg), Ca (92–258 mg), Zn (1.4 mg), Fe (1.2 mg), and Mn (0.8 mg). Albergamo et al. (2022) also reported potassium as the predominant mineral (214 mg), followed by Zn (31.58 mg), Fe (4.99 mg), and Mn (1.56 mg). Reda & Atsbha (2019) recorded the highest K and Ca seed contents (446.46 mg and 390.14 mg, respectively), with Fe (4.37 mg) and Zn (2.01 mg). Alsaad et al. (2019) found Ca (280.81 mg), Zn (52.90 mg), and Fe (3.63 mg). El-Safy et al. (2012) reported K (280 mg), Ca (58.50 mg), Fe (13.41 mg), Mn (6.13 mg), and Zn (1.36 mg).

El-Bilbeisi (2025) and Hassan et al. (2023) emphasized that iron is an essential micro-mineral in human nutrition, and its deficiency leads to disorders such as anemia. The observed differences in the mineral content of prickly pear parts reported by different authors may be attributed to cultivar differences and environmental conditions.

Based on the results of this study and previous research on *Opuntia* composition, the fruit pulp, seeds, and peels can be considered good sources of minerals (Table 7), particularly potassium, calcium, iron, and zinc.

TABLE 7. Mineral content (mg/100g) of prickly pear pulp, peels and seeds have been determined on dry weight basis.

Material	Minerals (mg/100 g sample Dry Matter)				
	Ca	Fe	K	Mn	Zn
pulp	407.45^{a}	12.49^{c}	603.81^{a}	0.72^{c}	12.04^{a}
peels	183.66^{c}	27.55^{b}	108.94^{c}	0.91^{a}	2.26^{c}
Seeds	255.00^{b}	53.55^{a}	419.00^{b}	0.77^{b}	3.71^{b}
SE±	0.03	0.01	0.03	0.01	0.01

a, b and c: Means having different superscripts within each column are significantly different ($p < 0.001$).

SE: standard error

Bioactive constituents of prickly pear parts

In recent years, researchers have shown increasing interest in natural products that may reduce the harmful effects of environmental toxins and help prevent the development of various human diseases. Many fruits and vegetables have been studied and identified as rich sources of nutraceutical compounds (Madrigal-Santillán et al., 2013).

All parts of the cactus plant are rich in polyphenolic compounds, including various flavonoids and phenolic acids. In the present study, the fruit pulp contained the highest total phenol content (889.34 mg/100 g), followed by the peels (423.95 mg/100 g), while the seeds contained 242.54 mg/100 g (Table 8). Our results were within the range reported by Belviranlı et al. (2019), who determined polyphenol levels in the fruit pulp as 490.74–932.87 mg/100 g. However, when compared with the findings of Belhadj-Slimen et al. (2020) (48.4–218.8 mg/100 g), Elshehy et al. (2020) (123.56 mg/100 g), and El-Mostafa et al. (2014) (218.8 mg/100 g), the total phenol content obtained in this study was considerably higher. Other studies have reported much lower levels of total phenols in prickly pear pulp, such as 45.70 mg/100 g (Asma et al., 2017) and 89.8 mg/100 g (Díaz et al., 2017).

The total phenol content of the peels in this study was consistent with the findings of Belhadj-Slimen et al. (2020) (45.70–425.59 mg/100 g), but higher than the values reported by García et al. (2020) (5.4–6.2 mg/100 g), Parafati et al. (2020) (17.1 mg/100 g), and El-Mostafa et al. (2014) (45.7 mg/100 g). Regarding the seeds, Belhadj-Slimen et al. (2020) and El-Mostafa et al. (2014) reported very low levels of total phenols (9 mg/100 g).

Antioxidants content

Antioxidants are receiving increasing attention due to their preventive roles in food and pharmaceutical products against oxidative deterioration, and in the human body against oxidative stress–mediated disease processes (Gulcin, 2020).

Regarding the pulp, our results were within the ranges reported by Alsaad et al. (2019) (36.5–78.1%) and close to that recorded by Elshehy et al. (2020) (39.18%), but lower than that described by Chaouch et al. (2016) (46.32%). Conversely, the result of the present study was higher than those reported by Mabrouki et al. (2015) and Abd El-Razek and Hassan (2011) (11.54% and 28.68%, respectively).

As for the antioxidants in the peels, our result was within the range reported by El-Beltagi et al. (2023) (45.45–98.73%). However, Elhassaneen et al. (2016) and Anwar and Sallam (2016) recorded lower antioxidant levels in the peel (71.05% and 62.14%, respectively). By contrast, Mahloko et al. (2019) described a much lower antioxidant content (11.15%) compared to the present study. Our results for the seeds were in agreement with Reda & Atsbha (2019), who reported a range of 43–95%, and were close to those stated by Alsaad et al. (2019) (46.5–81.3%). Similarly, Ali et al. (2020) recorded total antioxidant levels of 62.76%.

Vitamins content

Opuntia ficus-indica was found to contain vitamins at varying levels and is considered a valuable source of ascorbic acid (vitamin C). Vitamin C has been reported to exert positive health effects, including enhancing the immune system and reducing the risk of chronic and cardiovascular diseases. In the present study (Table 8), the vitamin C content was 165.40 mg, 46.36 mg, and 15.65 mg per 100 g for the fruit pulp, peels, and seeds, respectively. These values are higher than those reported by Bellache et al. (2022), who recorded 34–40 mg in the pulp; Kamble et al. (2017), who reported 20–30 mg in the green prickly pear and 24.1 mg in the orange prickly pear; and Feugang et al. (2006), who recorded a range of 12–81 mg/100 g. Similarly, Inglese et al. (2017) reported 24.1–28.0 mg/100 g, while El-Mostafa et al. (2014) found 18–30 mg/100 g in prickly pear fruits. Notably, the vitamin C content of prickly pear is higher than that of other common fruits such as apples, bananas, or grapes. For the peels, El-Hassan et al. (2022) reported higher vitamin C levels (74.59 mg) than those found in our study. García et al. (2020) also reported 59.8 mg, while El-Said et al. (2011) recorded 288.67 mg. In contrast, Manzur-Valdespino et al. (2022) described lower vitamin C content in the peels (27.3 mg) compared to our results. Few studies have assessed the vitamin C content of prickly pear seeds. Bellache et al. (2022) and El-Mostafa et al. (2014) both reported values of approximately 106 mg/100 g, which are considerably higher than our findings. Regarding vitamin E, the present study showed that the pulp contained significantly higher levels compared to the peels and seeds, measuring 9.31 mg, 0.15 mg, and 0.82 mg per 100 g, respectively. These results are lower than those of Bellache et al. (2022) and El-Mostafa et al. (2014), who reported 527.4 mg for the pulp, 2182 mg for the peels, and 106 mg for the seeds. Conversely, Elshehy et al. (2020) and Feugang et al. (2006) recorded much lower vitamin E levels in the pulp (96.8 and 111–115 µg/100 g, respectively).

Pigments

β- carotene and Anthocyanin content

The deep orange or yellow color of the prickly pear fruit indicates its richness in β-carotene. β-Carotene is a precursor of vitamin A, which is essential for maintaining healthy vision and skin. Epidemiological studies have demonstrated that a high intake of carotenoid-rich fruits and vegetables, as well as elevated blood levels of β-carotene, are associated with a reduced incidence of certain cancers due to its antioxidant properties and its ability to scavenge free radicals (Loukili et al., 2024; Liu et al., 2020; Toplu et al., 2009). In the present study, the β-carotene content in the pulp was markedly higher than the values reported in previous studies by Elshehy et al. (2020), Belviranlı et al. (2019), and Feugang et al. (2006), who recorded 28.01 µg/100 g, 4.09–13.07 µg/100 g, and 1.2–3.0 µg/100 g, respectively. According to Elhassaneen et al. (2016), the β-carotene content in prickly pear peels was higher than that in the pulp, with the highest reported value of 217.11 mg/100 g. Comparable values were also reported by El-Beltagi et al. (2023) and El-Said et al. (2011), who recorded 11.7 mg/100 g and 12.76 mg/100 g, respectively.

Few studies have assessed the β-carotene content in prickly pear seeds. Chaalal et al. (2013) reported approximately 0.67 mg/100 g, which is very close to the result obtained in the present study.

Anthocyanin represents another important class of plant pigments, being water soluble and effective in reducing oxidative damage (El-Beltagi et al., 2023). In the current study (Table 8), the pulp exhibited the highest anthocyanin content (3.68 mg/100 g), followed by the seeds (0.40 mg/100 g) and the peels (0.38 mg/100 g). However, El-Beltagi et al. (2023) reported a much higher anthocyanin content in the peels (9.62 mg/100 g).

Application of prickly pear fruit (*Opuntia ficus-indica*) in some food products

Table 9 and Fig. 2 summarize the organoleptic properties of products containing different substitution levels of prickly pear pulp, seed, and peel powders. The results showed that the mean sensory scores for all evaluated attributes were above the reference value of 8, which corresponds to the panelists' description of "like very much." Both biscuits prepared with 20% prickly pear peels and cakes enriched with 20% and 30% peel powder obtained the highest overall acceptability scores compared with other samples. Biscuits with 20% prickly pear peels received the highest flavor intensity scores among all products. Moreover, no significant differences ($p > 0.05$) were observed in texture attributes between the control cake and those containing 20% and 30% pulp or peel powder, nor in taste attributes between the juice samples. Overall, biscuits enriched with 20% prickly pear peel exhibited the highest acceptability across all sensory attributes.

TABLE 8. Bioactive components content of prickly pear pulp, peels and seeds have been determined on dry weight basis.

Material	Phenols (mg / 100 g Tanic acid)	Anti-Oxidant (%)	Vit C (mg/ 100 g Dry Matter	Vit E (mg / 100 g Dry Matter	ß-Carotene (mg / 100 g Dry Matter)	Anthocyanine (mg / g Dry Matter)
Pulp	889.34^{a}	43.41^{c}	165.40^{a}	9.31^{a}	1.81^{a}	3.68^{a}
Peels	423.95^{b}	88.23^{a}	46.36^{b}	0.15^{c}	1.71^{a}	0.38^{b}
Seeds	242.54^{c}	82.71^{b}	15.65^{c}	0.82^{b}	0.59^{b}	0.40^{b}
SE±	6.56	0.12	13.89	0.05	0.13	0.03

a, b and c: Means having different superscripts within each column are significantly different ($p < 0.001$).

SE: standard error

TABLE 9. Application of prickly pear fruit (*Opuntia ficus-indica*) in some food products.

	Treatments*	Color	Taste	Flavor	Texture	Overall acceptability
Cake	C	7.09^{b}	6.85^{b}	6.81^{b}	7.42	7.38^{b}
	Cp_{20}	7.47^{ab}	7.76^{a}	7.90^{a}	7.90	8.00^{ab}
	Cp_{30}	8.00^{a}	8.19^{a}	8.14^{a}	8.09	8.19^{a}
	Cj	7.76^{ab}	7.47^{ab}	7.57^{a}	7.61	7.90^{ab}
	SE±	0.23	0.27	0.24	0.25	0.24
	Treatments*	Color	Taste	Flavor	Texture	Overall acceptability
Biscuits	C	7.04^{c}	7.14^{c}	7.09^{c}	7.04^{b}	7.23^{b}
	Bp_{20}	8.28^{a}	8.14^{a}	8.19^{a}	8.14^{a}	8.28^{a}
	Bp_{30}	8.09^{a}	$7.95a^{b}$	8.00^{ab}	7.95^{a}	7.95^{a}
	Bj	7.47^{b}	$7.52b^{c}$	7.66^{b}	7.76^{a}	7.47^{b}
	SE±	0.16	0.15	0.15	0.14	0.14
	Treatments*	Color	Taste	Flavor	Texture	Overall acceptability
Noodles	C	7.19^{b}	6.85^{b}	6.76^{b}	6.76^{b}	6.85^{b}
	Np	7.85^{a}	7.66^{a}	7.76^{a}	7.57^{a}	7.71^{a}
	Ns	7.14^{b}	7.00^{b}	6.80^{b}	$7.14a^{b}$	7.14^{b}
	SE±	0.15	0.18	0.11	0.20	0.16
	Treatments*	Color	Taste	Flavor	Texture	Overall acceptability
Juice	Fresh juice	7.80^{a}	7.61	7.66^{a}	7.61^{a}	7.95^{a}
	$Syrup_{15}$	7.23^{b}	7.14	7.19^{b}	7.04^{b}	7.23^{b}
	$Syrup_{20}$	7.42^{ab}	7.28	7.28^{ab}	7.38^{ab}	7.71^{a}
	SE±	0.14	0.18	0.16	0.18	0.14
	Treatments*	Color	Taste	Flavor	Texture	Overall acceptability
Cerelac	C	7.42^{b}	6.80^{b}	6.71^{b}	7.09^{b}	7.09^{b}
	Cp_{20}	7.61^{ab}	7.47^{a}	7.61^{a}	7.71^{a}	7.76^{a}
	Cp_{30}	8.00^{a}	7.76^{a}	7.80^{a}	7.76^{a}	7.85^{a}
	SE±	0.17	0.17	0.16	0.18	0.17

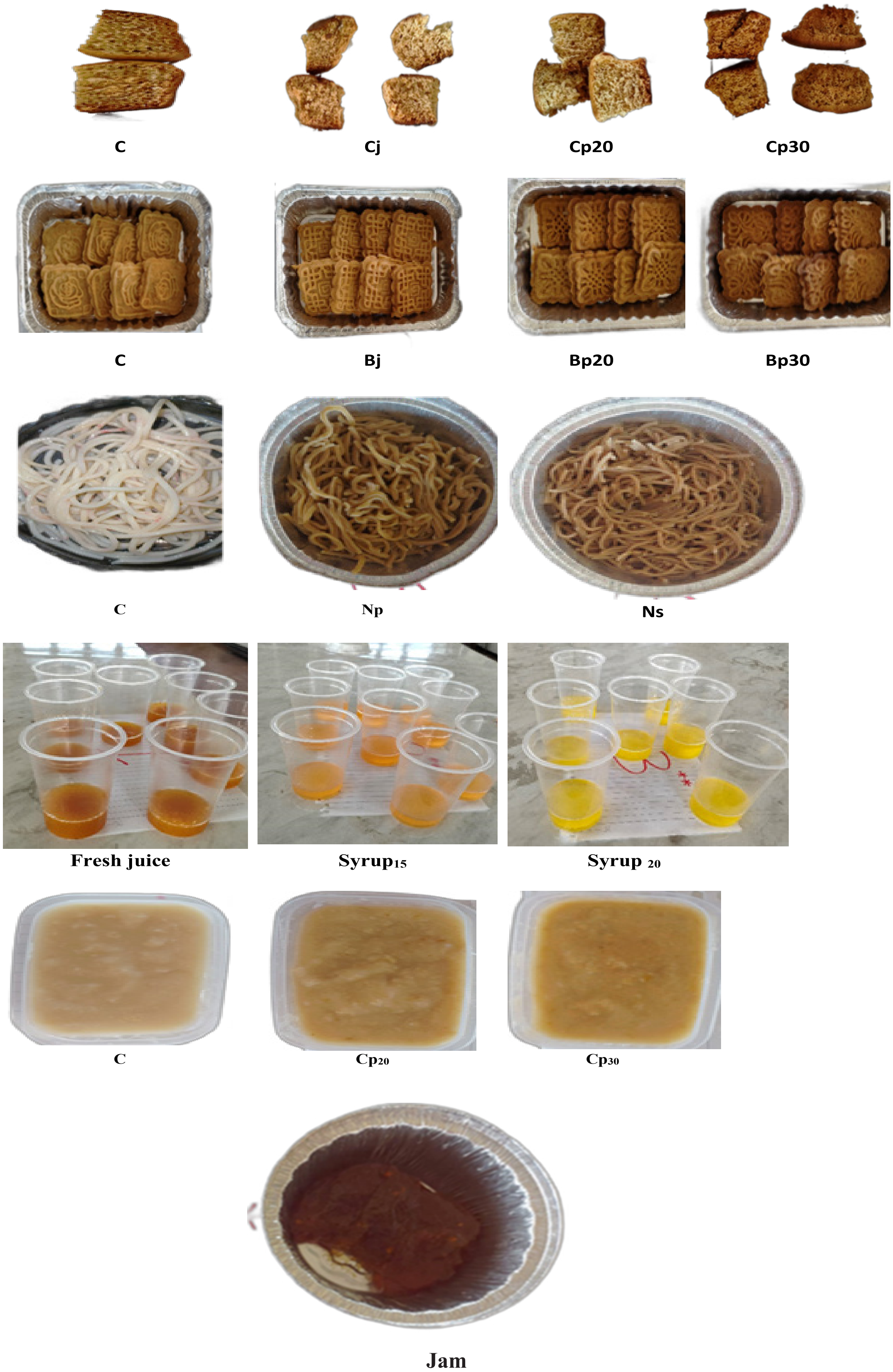

Fig. 2. Application of prickly pear fruit (*Opuntia ficus-indica*) in selected food products.

Conclusion

According to the findings of this study, prickly pear (*Opuntia ficus-indica*) is a rich source of dietary fiber, carbohydrates, phenolic compounds, and natural antioxidants, in addition to providing essential minerals and vitamins. Its high nutritional and bioactive composition highlights its potential as a functional food ingredient. Therefore, prickly pear can be considered a valuable component in the formulation of functional food products and may contribute to the prevention and management of several health-related conditions, including obesity, diabetes, and other chronic diseases.

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التين الشوكي (*Opuntia spp*.) كمصدر طبيعي للمركّبات النشطة بيولوجيًا لتدعيم الأغذية الوظيفية: دراسة شاملة من النواحي الكيميائية والتقنية والحسية

تُعدّ الوجبات المدعّمة بالألياف الوظيفية توجّهًا عالميًا متناميًا لما لها من دور فعّال في الوقاية من العديد من الأمراض المزمنة مثل السمنة، وداء السكري، وأمراض القلب والأوعية الدموية. تهدف هذه الدراسة إلى تقييم إمكانيات استخدام التين الشوكي (Opuntia spp.)، بجميع أجزائه (اللب، القشور، البذور)، كمصدر طبيعي للمركبات النشطة بيولوجيًا في تطوير أغذية وظيفية مدعّمة.

تم تحليل العينات لتحديد تركيبها الكيميائي، ومحتواها من المعادن، والبوليفينولات، والفيتامينات، والصبغات. أظهرت النتائج تباينًا في التركيب الكيميائي بين الأجزاء المختلفة للنبات؛ حيث تميز اللب بارتفاع محتوى الكربوهيدرات (٩٣,٣٨٪) والألياف (٦٨,٢٠٪)، بينما سجلت البذور أعلى نسب للبروتين (١٠,٦٦٪) والدهون (١٥,٤٠٪). أما القشور فاحتوت على أعلى تركيز من البيتا–كاروتين (١,١٧ مجم/١٠٠جم) ومضادات الأكسدة (٨٨,٢٣٪).

كما شملت الدراسة تقييمًا حسيًا لعدة منتجات غذائية وظيفية أُضيفت إليها نسب مختلفة من مكونات التين الشوكي، منها الكعك، والبسكويت، والمعكرونة، والسيريلاك، والمربى، والشراب. وقد بيّنت النتائج أن الكعك والسيريلاك سجلا أعلى درجات القبول عند إضافة ٣٠٪ من القشور، بينما كانت أفضل نسب القبول في البسكويت والمعكرونة عند ٢٠٪. سجلت جميع المنتجات فروقًا معنوية من حيث الطعم، والنكهة، والقبول العام.

تشير هذه النتائج إلى أن التين الشوكي يُعدّ مصدرًا واعدًا للمركبات النشطة بيولوجيًا التي يمكن توظيفها في تصنيع أغذية وظيفية ذات قيمة صحية مضافة