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Physicochemical and Biochemical Study of Different Parts of *Opuntia Ficus Indica* L (Fruit Juice, Cladodes and Seeds) and their Valorization in the Agri-Food Industry

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ABSTRACT: *Opuntia ficus indica*, native to Mexico's arid and semi-arid regions, is valued for its edible fruits, thorny cladodes that serve as natural livestock fences, and its water-purifying properties. As a drought-adapted plant, it holds significant nutritional and industrial potential. This study examined the composition focusing on water, dry matter, ash, organic acids, sugars, proteins, fats, and minerals. Carbohydrates were the predominant compounds, accounting for 13.83% in fruit juice and 5.65% in cladodes. Ash contents were $0.44 \pm 0.02\%$ in cladodes, 0.53% in fruit juice, and 1.52% in seeds. Seeds proved particularly rich, containing 5.93% protein, 9.4% fat, and 80.3% total dry extract, while cladodes presented $92.5 \pm 1.29\%$ moisture. This study provides novel data on Algerian plants, underscoring seeds as a promising source of high-value in cosmetic, and pharmaceutical industries. At the same time, cladodes offer low-cost nutritional resources for arid regions.

INTRODUCTION

Opuntia ficus indica is a shrub native to Mexico and grows in many dry and semi-arid regions of the world, such as South America and South Africa. Cultivated and wild forms of the plant exist in several regions of the world ¹. *Opuntia ficus indica* presents an important food source; all components of the cactus (flower, cladodes, and fruit) constitute vital foods if they come from a natural plantation. For animals, the cladodes are highly digestible and contain high levels of vitamins, iron, and beta-carotene ². In human nutrition, cactus fruits and cladodes are consumed as vegetables, salads, soups, and preserves. They can also be used for making jam and fruit juice ³.

The valorization of natural resources in developing countries could constitute a solution for socio-economic progress. Nevertheless, choosing an appropriate valorization method requires prior knowledge of the plant's components. The cactus, or prickly pear, is a "magical" shrub that deserves to be valued in nutritional, dietary, therapeutic, and industrial terms. *Opuntia ficus indica* is, among other things, renowned for its medicinal properties. In the pharmacopoeia, it has been widely used topically to accelerate the healing of skin wounds, as well as internally to treat various gastrointestinal disorders and to lower blood glucose levels in diabetics ⁴. While the species *Opuntia ficus-indica* have been studied previously, few investigations provide a comprehensive comparative analysis of cladodes, fruit juice, and seeds from the same Algerian ecotype, with an explicit link between composition and practical valorization potential in food, feed, nutraceuticals, and industry. ⁵

This work is based on the study of the physicochemical and biochemical characteristics of *Opuntia ficus indica*. This study focuses on determining the average contents of the main constituents in various products of the plant: cladodes, fruit juice, and seeds; specifically, the levels of dry matter, ash content, organic acids, sugars, proteins, fat, water, and mineral elements. Comparative evaluation enables identification of part-specific applications (seeds for oil extraction, cladodes for forage/vegetable use), supporting sustainable utilization in arid/semi-arid regions.

MATERIALS AND METHODS

Plant Material

The cladodes of *Opuntia ficus-indica* L., was collected from the region of Mascara (35° 23'23" N and 00° 07' E). It was identified by Prof. Zahafi B., from the University of Mustapha Stambouli, Mascara. The average temperature of this area is 15°C. The hottest months reach 35 to 40°C, and the coldest 0 to 7°C. Cladode and fruit collection was carried out in May and June. The voucher specimen of *Opuntia ficus-indica* (OFI -0909AB) has been deposited in the Laboratory of Pharmacognosy and Botany at the University of Mentouri, Constantine, Algeria.

Sample preparation

Fresh cladodes of *Opuntia ficus-indica* were thoroughly washed under running tap water to remove dust and debris, carefully de-spined, diced into small pieces, and subsequently oven-dried at 50 °C until a constant weight was achieved. Mature fruits were manually peeled to separate the pulp from the outer skin, after which the pulp was mechanically fruit juiced to obtain the fruit juice. The seeds were then carefully isolated from the remaining pulp residue, washed with distilled water to remove adhering mucilage and pulp fragments, and finally air-dried to constant weight before further analysis.

Physicochemical analyses

The different parts of the cactus (cladodes, fruit juice, and seeds) are analyzed for their pH, total dry extract, moisture content, ash content, and titratable acidity.

pH Determination

The pH is measured potentiometrically with a calibrated digital pH meter and glass electrode at 20°C. Fruit juice is analyzed directly or after dilution (1:9). Cladodes are cleaned, chopped, and homogenized (1:5 w/v with water) then filtered. Seeds are ground into powder and prepared as 1:10 aqueous suspension. Measurements should be done promptly on fresh samples.⁶

Total dry extract content

Total dry extract is determined gravimetrically by oven drying. A known weight of homogenized fruit juice (5 g), chopped cladodes, or ground seed powder is placed in a pre-weighed dish and dried at 105°C to constant weight. After cooling in a desiccator, the dry residue is weighed. Percentage total dry extract is calculated as [(dry residue weight / initial sample weight) × 100]. For juices, total soluble solids (°Brix) can be measured directly using a refractometer.⁶

Moisture Content

Moisture content is determined by the loss-on-drying method. Fresh homogenized juice, chopped cladodes, or ground seeds (5 g) are weighed in a pre-dried dish and oven-dried at 105°C to constant weight. Moisture (%) is calculated as [(initial weight – dry weight) / initial weight] × 100. The procedure is performed on fresh material in triplicate.⁶

Ash Content

Ash content is determined by incineration. 5 g of sample in a pre-weighed crucible is charred then ashed in a muffle furnace at 550°C until constant weight of white/gray residue is obtained. Ash content (%) is calculated as [(ash weight / dry sample weight) × 100].⁶

Titratable Acidity

Titratable acidity is measured by acid-base titration and expressed as citric acid. 10 mL of fruit juice (or aqueous extract of cladodes/seeds) is diluted with distilled water and titrated with standardized 0.1 N NaOH to pH 8.1. TA (% citric acid) = $(V_{\text{NaOH}} \times N_{\text{NaOH}} \times 0.064 \times 100) / \text{sample volume (mL)}$. Analyses are performed in triplicate.⁶

BIOCHEMICAL ANALYSES

Determination of protein content (Kjeldahl method)

Unlike sugars and lipids, proteins contain nitrogen. This property will be exploited in the method for determining the protein content in foods. The Kjeldahl method is the reference method for determining protein content in foods.⁷ Approximately 0.5–1.0 g of dried and ground sample (cladodes or seeds) was weighed into a Kjeldahl digestion flask. 25 mL of concentrated sulfuric acid (H_2SO_4 , 18 mol/L) was added along with a catalyst mixture (potassium sulfate and copper sulfate) to facilitate digestion. The mixture was heated gradually on a digestion block to avoid foaming, then boiled vigorously until the digest became clear and greenish (indicating complete conversion of organic nitrogen to ammonium sulfate). After cooling, the digest was diluted with distilled water and transferred to a distillation unit. Sodium hydroxide solution (40% NaOH, 60 mL) was added to liberate ammonia, which was distilled into a receiving flask containing boric acid solution. The distillate was then titrated with standardized hydrochloric acid (HCl, 0.1 mol/L) until the endpoint. Nitrogen content was calculated from the titer volume, and crude protein was obtained by multiplying the nitrogen percentage by the conventional factor of 6.25.

Determination of fat content (Soxhlet Method)

The Soxhlet method is a gravimetric method, as the sample is weighed at the beginning and the fat at the end of the extraction⁸. Dried and ground samples (5 g of cladodes or seeds) were accurately weighed and placed into a cellulose extraction thimble. The thimble was inserted into a Soxhlet extractor fitted with a pre-weighed round-bottom flask containing n-hexane as the solvent. Extraction was performed continuously for 6–8 hours on a heating mantle maintained at 65°C to ensure steady solvent reflux. After extraction, the solvent was evaporated from the flask using a rotary evaporator. Fat content was calculated as the percentage difference in flask weight before and after extraction, expressed on a dry matter basis.

Determination of the content of reducing and total sugars

For the analysis of total sugars, we used the method of Dubois et al.⁹. The principle of this method is that, in an acidic, hot medium, the glycosidic bonds of the carbohydrates are hydrolyzed. The simple sugars thus released undergo intramolecular dehydration to give furfural derivatives. The aldehyde function of furfurals Condenses thus in acidic media with the hydroxyl group of a phenolic compound to give reddish-colored acetals or hemiacetals that absorb in the visible range (450–500 nm).

Determination of mineral salts (K, Na, Ca) by flame spectrophotometer

Mineral elements were quantified in the cladodes using flame photometry. The flame photometer is based on the fact that any atom at an excited energy level emits characteristic radiation when it returns to the ground state. The excitation of the atoms is achieved through heat. The measurement is carried out on a chosen line and at concentrations such that the intensity is proportional to its concentration¹⁰. Dried cladode samples were first ashed (dry ashing at 500–550 °C), and the ash was dissolved in dilute hydrochloric acid to prepare a clear extract. Appropriate aliquots of the extract were diluted with distilled water. Calibration was performed using a series of standard solutions containing known concentrations of K, Na, and Ca. The diluted sample solutions were aspirated into the flame photometer (using appropriate wavelengths: ~766 nm for K, ~589 nm for Na, and ~423 nm for Ca), and emission intensities were recorded. Concentrations were determined from calibration curves, with appropriate blank corrections and dilution factors applied to express results as mg/100 g or as percentage on a dry-matter basis.

Statistical analysis

All analyses were performed in triplicate (n=3 independent determinations per parameter). Data are presented as mean $\pm$ standard deviation (SD). One-way ANOVA was conducted in GraphPad Prism 5, with Tukey's post hoc test for multiple comparisons where applicable. Significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Physicochemical analyses

The physicochemical properties of the samples were thoroughly evaluated to assess their quality, and compliance with relevant standards.

pH

The results of our experimental study reveal differences in pH across the plant's different parts. The fruit juice's pH is 6.11, which is very close to neutral; however, the cladodes' pH is acidic at 4.57 (Figure 1). These values are comparable to those of the cladodes studied by ¹¹ and the fruit juice studied by ². This pH property can be considered a parameter that classifies prickly pear as a slightly acidic foodstuff suitable for culinary use.

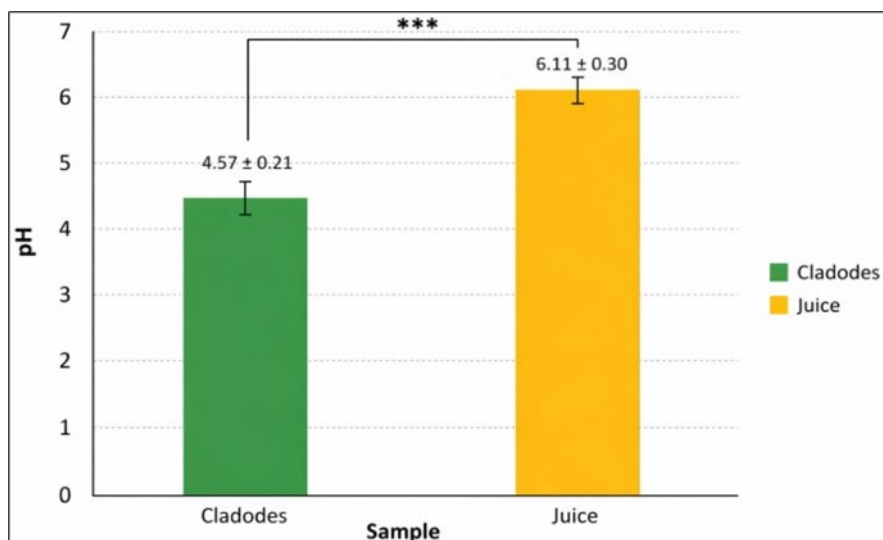


Figure 1. Evaluation of the pH in cladodes and fruit juice.

The pH values obtained in the present study, 4.57 for the cladodes and 6.11 for the fruit juice, are consistent with ranges reported in the literature for *Opuntia ficus-indica*. For cladodes, the acidic pH of 4.57 aligns closely with values around 4.6 commonly documented in fruit juices or extracts. This is supported by comprehensive reviews and studies indicating fruit juices typically exhibit a pH of 4.6, attributable to organic acids such as malic acid (predominant due to crassulacean acid metabolism) and lesser amounts of citric and oxalic acids. For instance, Martins et al. ²⁷ reported fruit juice pH values around 4.6 in their review of physicochemical properties, classifying cladodes as low-acid vegetables suitable for culinary applications. Similarly, Hadj Sadok et al. ¹¹ and related studies on cladode composition describe comparable acidic profiles (e.g., pH $\approx 4.76 \pm 0.97$ in some fruit juice preparations), reflecting regional ecotypes and maturity stages.

For fruit juice, the near-neutral pH of 6.11 falls within the typical range for prickly pear fruit juice, which is generally low in titratable acidity (0.02–0.18% citric acid equivalents) and exhibits pH values from approximately 5.5 to 6.5 (or up to 6.4–6.5 in Sicilian varieties). This near-neutral character classifies prickly pear fruit juice as a low-acid food, as noted in multiple studies. ²⁸ The slightly lower value here (6.11) may reflect varietal differences, maturity at harvest, or processing, but remains in good agreement with Mediterranean and Algerian-sourced fruits.

The observed pH values highlight the technological potential of different plant fractions. The near-neutral pH of the fruit juice (6.11) is particularly favorable for the development of functional beverages and jam products, as it provides a mild taste profile and reduces the need for excessive acidification. However, this low acidity also suggests greater susceptibility to microbial spoilage, underscoring the need for appropriate preservation techniques (such as pasteurisation, refrigeration, or mild acidification). In contrast, the acidic pH of cladodes (4.57) supports their use in minimally processed vegetable products and fermented foods, where mild acidity can enhance microbial stability and flavour development.³¹

Total dry extract

According to the analyses conducted. It is noted that the dry extract rate varies from one part to another, depending on the composition of organic and mineral matter, and we obtained the results shown in the following histogram. These results show that the total dry extract rate is very high in the seeds (80.3%) and low for the fruit juice and cladodes (Figure 2).

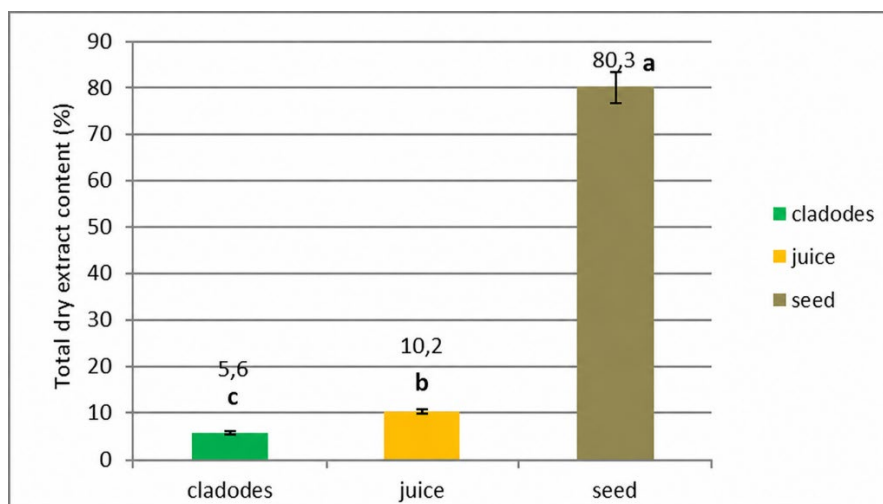


Figure 2. Evolution of the total dry extract content in cladodes, fruit juice, and seed. The letters (a, b, c) indicate significance difference among the studied accession ($p < 0.05$).

The seeds valorization and exploitation for industrial purposes can be considered, particularly as a source of metabolites and as animal feed. The low dry matter content of the cladodes observed in this study could be largely explained by the cladode's mucilage, a hydrophilic mucus with a high water-retention capacity within the cladodes, particularly during long periods of drought.¹²

The high dry matter content of seeds (80.3%) indicates a strong potential for industrial valorization as a concentrated raw material, particularly for oil extraction and production of protein-rich by-products. This fraction is especially suitable for cosmetic, pharmaceutical, and nutraceutical applications. Conversely, the low dry extract in cladodes and fruit juice reflects their high-water content, making them more appropriate for fresh consumption, rehydrated animal feed, and low-calorie food formulations.³²

Moisture content

According to analyses of different plant parts, the average moisture content varies from one part to another. These moisture analysis results show that the cladodes and fruit juice are very rich in water, with average contents of $92.5 \pm 1.29\%$ and 86.2% , respectively (Figure 3). In contrast, the seeds exhibit a low water content due to their dormancy. These values are comparable to those of the cladodes studied by¹¹ and the fruit studied by².

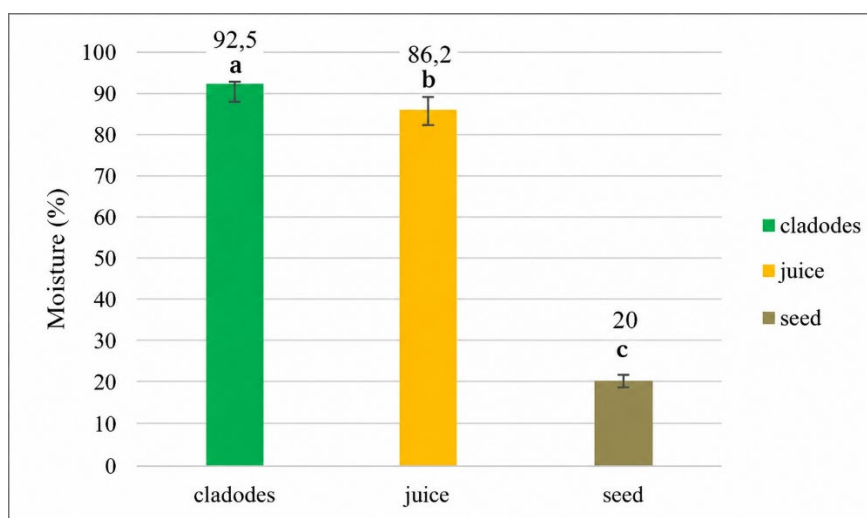


Figure 3. Evaluation of the moisture content in cladodes, fruit juice, and seeds. The letters (a, b, c) indicate significance difference among the studied accession ($p < 0.05$).

The cladodes of *Opuntia ficus-indica* displayed exceptionally high moisture content ($92.5 \pm 1.29\%$), a feature that strongly supports their adaptation to arid and semi-arid environments. This elevated hydration is largely attributable to mucilage, a complex polysaccharide hydrocolloid abundant in the cladodes. As highlighted by Sáenz et al.²⁹, *Opuntia* mucilage exhibits remarkable water-absorption and retention capacity due to its hydrophilic nature and ability to form viscous gels, enabling the plant to store substantial amounts of water during prolonged drought periods and survival under water stress.

In arid and semi-arid regions, cladodes represent a valuable low-cost forage resource for livestock, particularly during drought periods when conventional feed is limited. However, high moisture also limits shelf life, requiring drying, fermentation, or preservation technologies for industrial applications.³³

Titration acidity

Acidity is represented by the set of organic acids (citric, malic, tartaric, etc.) and minerals that impart a sour taste when ionized. The analysis of titratable acidity indicated that the citric acid content in the fruit juice is relatively high. This acidity level, along with the fruit's physicochemical profile, exposes it to potential microbiological alterations and contributes to its limited shelf life if not properly preserved. Fruit juice contains phenolic acids and organic acids.¹³⁻¹⁶

Higher acidity levels in fruit juice, such as those observed in the present study, have occasionally been documented in certain cultivars or less mature fruits, particularly from Algerian and Moroccan ecotypes, where values can depend on variety, ripening stage, and environmental conditions.^{41,42}

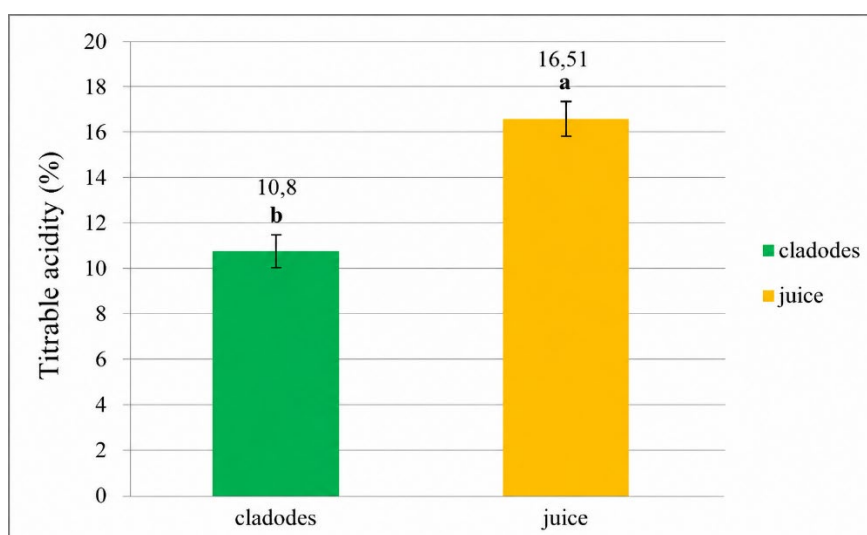


Figure 4. Evaluation of the titratable acidity in cladodes and fruit juice. The letters (a, b) indicate significance difference among the studied accession ($p < 0.05$).

Ash content

It is found that ash content varies considerably across the different products of the plant, with the lowest in the cladodes and fruit juice and the highest in the seeds (Figure 5). According to these results, the seeds of the prickly pear are the part that contains a high amount of mineral salts.

The elevated ash content in seeds reflects their mineral richness, suggesting potential use in mineral-enriched animal feed supplements. However, the relatively high mineral concentration may require controlled inclusion rates to avoid dietary imbalance in livestock formulations. Cladodes with moderate ash content are suitable for human nutrition and forage applications, providing essential minerals without an excessive mineral load.³⁴

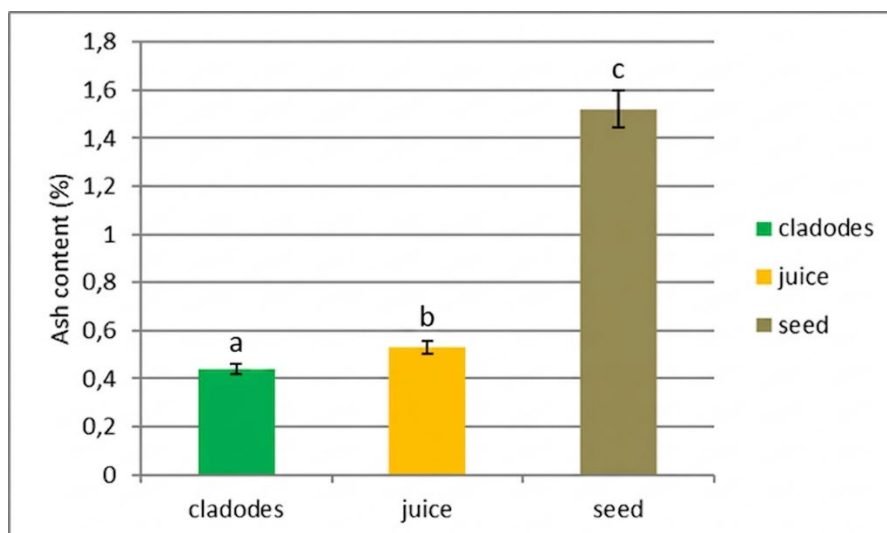


Figure 5. Evaluation of the ash content in cladodes, fruit juice, and seeds. The letters (a, b, c) indicate significance difference among the studied accession ($p < 0.05$).

Mineral content

Through the analysis of mineral salts, the cladodes of *Opuntia ficus indica* contain relatively significant amounts of mineral elements, particularly potassium and calcium. Sodium is present at trace levels and decreases during pad growth (Figure 6). These values are comparable to those of the cladodes studied by ¹¹. The cladodes is a rich source of vitamin C, vitamin E, β -carotene, and minerals. ¹⁷⁻¹⁹

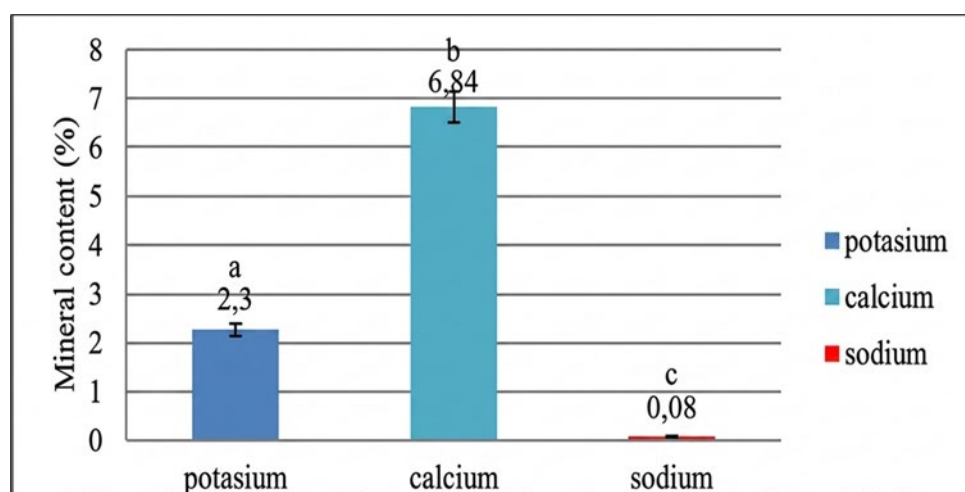


Figure 6. Evaluation of the mineral content in the cladodes. The letters (a, b, c) indicate significance difference among the studied accession ($p < 0.05$).

The cladodes were found to be relatively rich in key mineral elements, particularly potassium (K) and calcium (Ca), with low sodium levels. These mineral profiles align with previous findings and underscore nutritional benefits. Hernández-Urbiola et al. ²⁰ demonstrated, through detailed chemical analysis of organic prickly cladodes at varying maturity stages, that *O. ficus-indica* cladodes serve as an important dietary source of calcium, with content increasing in older cladodes and reaching levels that make them a viable alternative for populations with limited access to dairy products or those facing lactose intolerance. The bioavailable calcium, often present as calcium oxalate or other forms, supports bone health and may help prevent osteoporosis by maintaining bone mineral density, especially when combined with adequate vitamin D and other cofactors. The high K content further promotes cardiovascular health and electrolyte balance, while the low Na enhances suitability for low-sodium diets. ¹⁸

Hernández-Urbiola et al.²⁰ considered cladodes an important source of calcium for populations with low dairy product availability and for people with difficulty digesting dairy products. The cladodes are considered a good source of minerals, namely potassium, magnesium, calcium, and sodium.¹⁰ The presence of magnesium and calcium makes prickly pear useful for preventing osteoporosis.²¹

The mineral profile of cladodes, particularly their high potassium and calcium and low sodium content, makes them highly suitable for functional foods targeting cardiovascular health and electrolyte balance. Their calcium content also supports their use as a plant-based alternative to dairy-derived calcium supplements, particularly in lactose-intolerant populations. From an industrial perspective, cladodes can be developed into mineral-fortified powders, dietary supplements, and functional ingredients for health-oriented food products.³⁵

Biochemical analyses

The biochemical composition of the samples was determined to evaluate their nutritional quality and potential applications. These analyses focused on key macronutrients and provided important insights into the overall value and functionality of the studied material.

Proteins and fat contents

Unlike the cladodes, which contain a low fat and protein content, the seed is a part rich in fat with an average content of 9.4% (Figure 7). Because seeds are low in water and high in fat, it is a general observation for all plant products that when the water content is high, the fat content is low, and vice versa (inversely proportional).⁴⁰ This part can therefore be exploited for pharmaceutical, medical, and cosmetic uses. Recently, cactus seed oil (*Opuntia ficus-Indica* L.) has been introduced as a new ingredient capable of quickly finding its place in the high-value cosmetics field, mainly due to its ideal chemical composition for cosmetic applications.²²

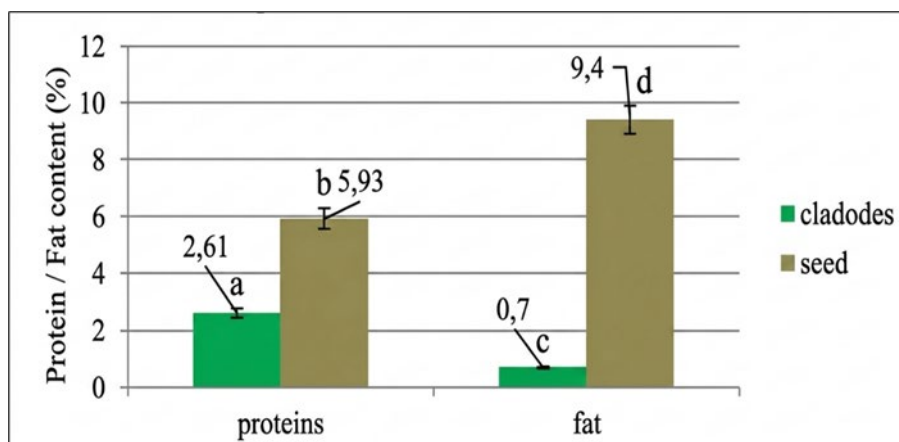


Figure 7. Evaluation of the protein and fat content in the cladodes and seeds. The letters (a, b, c, d) indicate significance difference among the studied accession ($p < 0.05$).

The seeds of *Opuntia ficus-indica* exhibited markedly higher fat (9.4%) and protein (5.93%) contents than the cladodes, which showed lower values (typically $0.7 \pm 0.02\%$ fat and $2.61 \pm 0.01\%$ protein). This inverse relationship, high lipid and protein accumulation in seeds versus low levels in cladodes, is characteristic of many plant species, where seeds serve as energy and nutrient storage organs for germination. In contrast, cladodes prioritize water retention (via mucilage) and photosynthetic efficiency in arid environments.³⁹

The seed fat content of 9.4% aligns well with reported ranges for Mediterranean and Algerian ecotypes. Literature indicates seed oil yields of approximately 7–15% (on whole seed weight basis), varying by geographic origin, cultivar, maturity, and extraction method.³⁸ For Algerian varieties, Chougui et al.³⁰ documented oil contents around 7.3–9.3% in certain ecotypes, with fatty acid profiles dominated by unsaturated acids (especially linoleic acid ~50–65%, oleic ~15–25%).

In contrast, the cladodes' low fat ($0.7 \pm 0.02\%$) and protein ($2.61 \pm 0.01\%$) reflect their primary role as hydrated, low-energy structural and forage tissues (high moisture $92.5 \pm 1.29\%$, carbohydrates dominant). Protein levels in cladodes generally range from 2–10%, making them suitable mainly as low-protein forage or vegetable rather than concentrated nutrient sources.

Overall, the compositional contrast highlights part-specific applications: seeds as a premium lipid/protein-rich fraction for oil-based products and cladodes for bulk nutritional support in animal feed or human diets in water-scarce regions.^{22,30}

The high lipid content of seeds (9.4%) combined with moderate protein levels positions them as a promising raw material for the production of cold-pressed edible oils. *Opuntia* seed oil, rich in unsaturated fatty acids, is particularly valuable in the cosmetic industry (anti-ageing creams, skin repair formulations) and pharmaceutical applications due to its antioxidant properties.³⁸ Protein-rich seed residues (cake) after oil extraction can also be valorized as functional feed ingredients or protein supplements. In contrast, cladodes contain low lipid and protein levels, making them unsuitable as concentrated nutrient sources but ideal for low-calorie vegetable products and bulk forage feed, especially in resource-limited environments.³⁶

Reducing and Total Sugars

These results indicate that the fruit juice is rich in sugars, which are indicators of high energy value (Figure 8). These sugars are in greater quantity in the fruit juice than in the cladodes. This high sugar content in the fruit juice is used to make a jam at the lowest possible cost, which is easy to prepare and poses no material concerns for users. Mucilage is a polysaccharide derived from cladodes and the peel of the fruit, used as an edible coating to preserve food.^{12,23}

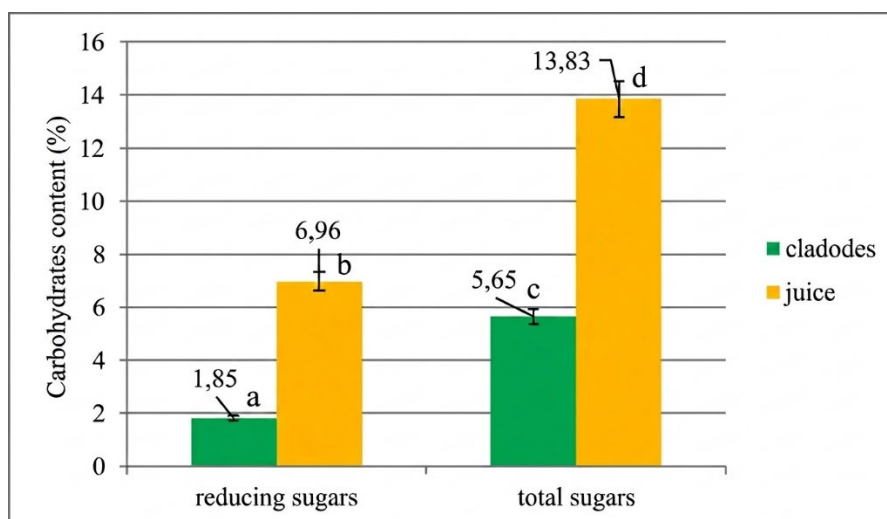


Figure 8. Evaluation of the rates of reducing and total sugars in cladodes and fruit juice. The letters (a, b, c, d) indicate significance difference among the studied accession ($p < 0.05$).

The high sugar content in fruit juice confirms its suitability for industrial processing into jams, syrups, fermented beverages, and natural sweeteners. Its sugar profile enhances fermentability, making it suitable for bio-based fermentation industries as well. Additionally, mucilage derived from cladodes and fruit peel, composed of complex polysaccharides, has strong potential as a natural edible coating and biodegradable packaging material. Its film-forming, emulsifying, and water-retention properties make it attractive for food preservation, extending shelf life, and reducing the use of synthetic packaging.³⁷

Estimation of the energetic value of cladodes

We deduced it from the contents of assimilable carbohydrates, lipids, and proteins, assigning each gram of these various substances the ability to provide 4 calories if it is carbohydrates or proteins and 9 calories if it is lipids. These figures are rounded coefficients obtained by averaging the results of experiments on a large number of foods. There are more specific coefficients applicable to certain food categories, particularly fruits. However, we were not allowed to apply these coefficients to the substances we studied. The prickly pear, with its large number of seeds, appears quite different from other fruits.

On the other hand, the application of rounded coefficients therefore has every chance of yielding results closer to reality than those of specific coefficients. The analysis of the cladodes was presented in Table 1. It is therefore almost certain that 100 grams of prickly pear cladodes do not provide 44.5 calories, as the theoretical calculation would suggest, but only 27.8 calories provided by assimilable sugars and a very small proportion of lipids and proteins. The physicochemical analysis of the young

cladodes of *Opuntia ficus indica*, which highlights compositional similarities with widely used vegetables such as spinach, tomato, and lettuce, confirms the potential for use as animal feed and as a vegetable.

Table 1. Results of the physicochemical analysis.

	Content (% fresh weight)	Caloric Coefficients	Energy Values (kcal/100 g)
Moisture	92.5 ± 1.29		
Ash content	0.44 ± 0.02		
Total sugar	5.65 ± 0.03	×4	27.8
Proteins	2.61 ± 0.01	×4	10.44
Lipids	0.7 ± 0.02	×9	6.3
Total			44.5

The young cladodes, very rich in water (91-93%), are rich in calcium but have a low sodium content; these levels are comparable to those of spinach and tomato. Young cladodes can thus contribute significantly to meeting human nutritional needs. The young cladodes are also rich in total sugars (5.65%) and proteins, with a notable content (2.6%). Taking into account the average weight of "nopalitos" (80 to 100 g) used as a vegetable in Mexico and Chile, and the consumption model in Algeria based on plant-based sources. Vegetables (excluding potatoes) represent 246 to 265 g/day of the ration. The nutrient intakes relative to daily needs were determined for a consumption of 130 g of fresh stage 3 cladodes (105 g), which represents 50% of the daily vegetable intake. ²⁴ The use of cactus in industries and its study of nutritional composition and bioactive compounds is becoming increasingly important. ²⁵

The nutritional value of the cactus is primarily based on its content of vitamins C and E, carotenoids, fibers, amino acids, and large quantities of glucose and fructose. The prickly pears are also rich in phenols and flavonoids, which have hypoglycemic and antioxidant activity. ²⁶

Opuntia ficus-indica is recognized as a rich source of bioactive compounds with significant nutritional, functional, and pharmacological potential. The main classes include phenolic compounds, flavonoids, betalains, polysaccharides, and minerals. These contribute to its antioxidant, anti-inflammatory, hypoglycemic, and other health-promoting properties, supporting its valorization in food, nutraceutical, and industrial applications. ⁴³

The chemical composition and concentration of these bioactive compounds in *O. ficus-indica* vary significantly depending on environmental factors, genetic (ecotype/cultivar) differences, and developmental stage. This variability underscores the importance of characterizing local ecotypes for targeted applications. ⁴⁴

CONCLUSION

This comparative analysis of Algerian *Opuntia ficus-indica* underscores a marked functional differentiation among plant fractions, enabling targeted and efficient valorization strategies tailored to arid and semi-arid contexts. Cladodes stand out as a highly hydrated matrix rich in minerals. These traits position them as a low-cost nutritional resource, effective forage supplement for livestock in drought-prone regions, and a source of natural hydrocolloids or bioactive extracts. In parallel, the fruit juice demonstrates strong technological potential for processing into functional beverages, nectars, or natural colorants, thanks to high moisture content, natural sugars, and polyphenolic antioxidants that support good yield, stability, and sensory appeal. *O. ficus-indica* cladodes as a source of essential lipids can attribute a support for applications in nutraceuticals, and especially cosmetics, where it excels in skin barrier repair, hydration, and anti-aging formulations.

Funding declaration

There is no funding to declare.

Data availability statements

All data generated or analyzed during this study are included in this published article.

Compliance with ethical standards

Plant collection and field studies were conducted in accordance with institutional, national, and international guidelines. The voucher specimen of *Opuntia ficus-indica* (OFI-0909AB) is deposited in the Laboratory of Pharmacognosy and Botany, University of Mentouri, Constantine, Algeria.

Permission to collect

All required permissions and licenses for collecting *Opuntia ficus-indica* L. were obtained in compliance with applicable regulations.

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