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Effects of aqueous cactus (*Opuntia ficus-indica* (L.) Mill.) cladodes extract on wheat dough and pan bread quality characteristics

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Abstract
The effect of kneading wheat flour with aqueous cladode extracts on the dough's rheological and pan bread quality characteristics was investigated. Cladodes aqueous extract solutions of 5% and 7.5% positively and significantly ($P < 0.05$) impacted the dough's rheological properties as well as the bread-specific volume index. The use of 10% cladodes aqueous extract solutions, however, negatively impacts bread quality. As the cladodes extract increased from 5 to 10%, the L^* and b^* color values of both crust and crumb were reduced, a^* color values of crust significantly increased while decreased for the crumb. Sensory bread preferences formulated with 7.5% extract were assessed as the best, followed by 5% bread, while the lowest preferences were bread formulated with 10% extract. The use of 7.5% of cladodes aqueous extract resulted in the greatest specific volume and extensograph parameters, except the extensibility E; an indication of the significant impacts on bread quality. In particular, the Max height extensograph index was 426 when 7.5% of cladodes aqueous extract solution was used compared to 280 for the control and 396–365 for the 5 and 10% cladodes aqueous extract solutions, respectively. Results suggest the potential use of cladodes aqueous extract solutions as a healthy alternative to chemical additives in bread and baked products.

Keywords Bread quality · Cactus cladodes · Dough rheology · Sensory evaluation · Farinograph · Extensograph

1 Introduction

Opuntia ficus-indica (L.) Mill., cactus, belongs to the family *Cactaceae*; a tropical plant that grows in arid and semi-arid regions of the world including Latin America, Australia, India, South Africa, and the Mediterranean area [1]. The *Cactaceae* family was reported to contain more than 130 genera and nearly 1500 species.

Cactus is grown for its fruits and cladodes that are used as a source of nutrients and functional benefits. Cladodes have recently attracted attention in nutritional and pharmacological sciences due to their nutritional content including minerals, vitamins, protein, dietary fiber, mucilage, pectin, and antioxidant activities. More specifically [2], reported that cladodes are used to prepare value-added products such as wine, pickles, jam, squash, body lotions, creams, shampoo, and other products. Moreover, tender cladodes are used as fresh green vegetables and salads in some countries. Furthermore, In Mexico, cladodes are regularly served with meals, and they are deeply embedded in the culture like green beans [3].

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Cactus cladodes contain bioactive phytochemical compounds known for their health-related properties. It has been used in traditional folk medicine in treating several diseases and conditions, including diabetes, hypercholesterolemia, hypertension, rheumatic pain, asthma, and gastric mucosa diseases in many countries all over the world [1]. However, there is no report about the adverse/toxic effects of cactus cladodes on animals or humans, and it could be GRAS for consumption [1, 4]. Bread has been considered a staple food, among baked goods, for many civilizations. Its composition has an adequate balance of macronutrients and provides some micronutrients and minerals, therefore, its role in nutrition is fundamental [5]. Flour, water, salt, and yeast are the basic ingredients for bread making, however, other ingredients could be used to improve the quality and shelf life of this product such as flours of other cereals, malt, preservatives, emulsifiers, yeast foods, oxidizing agents, vital gluten, milk and milk products, and soya flour [6].

Pan bread, as an example of bread, could contain all these ingredients and other agents that may improve its characteristics including the texture, crust and crumb characteristics, loaf volume, and organoleptic properties. Moreover, many efforts were made to enhance the quality of wheat flour including the introduction of ozone gas as well as the use of natural plant extracts such as sumac aqueous extracts [7, 8].

In bread-making, the additives used are classed into four main categories: oxidants/reductants, hydrocolloids, emulsifiers, and preservatives. In each category, there are also many additives that are subcategorized, which improve the dough and bread characteristics. However, the use of natural additives would provide safer additives instead of chemical additives as well as adding a clean label. As a result of the use of such natural additions; some of the chemical bread-making additives were already prohibited or reduced [9].

Cactus cladodes powder could be used as a composite flour to replace wheat or maize flour in the making of bakery products such as bread, biscuits, and tortillas [10]. However, the use of cactus cladodes powder was reported to dilute gluten content that negatively impacted baked products (i.e., decreasing loaf volume) [11]. To the best of our knowledge, no information is available concerning the effects of aqueous cactus cladodes extract on the wheat pan bread formulation. Therefore, the current work aims to investigate the effect of using different aqueous extracts solutions of cactus (*Opuntia ficus-indica* (L.) Mill.) cladodes on the wheat dough rheological as well as pan bread quality characteristics.

2 Materials and methods

2.1 Preparation and characterization of cladodes aqueous extracts

Mature tender cladodes of cactus *Opuntia ficus-indica* (L.) Mill. domestically grown were randomly collected from different gardens in April (2023). The collected cladodes were botanically identified by plant taxonomists at the Department of Plant Production and Protection, Faculty of Agriculture, Al-Balqa, Applied University, Salt, Jordan.

Collected cladodes were washed, peeled, cut into small pieces, and dried in a convection oven at 40 °C ± 1 °C for 72 h until reaching a constant weight. The dried cladodes were ground using a kitchen grinder and sieved using wire sieves (0.35 mm pore). The obtained powder was kept refrigerated in airtight polyethylene bags until use.

Three concentrations of cladodes powder (i.e., 5%, 7.5%, and 10%) were prepared by combining the prepared cactus powder with deionized distilled water (w: v). The mixtures were held at room temperature (20–25 °C) for 24 h to allow for additional extraction and then filtered through white cheesecloth. For subsequent characterization, dough kneading, and pan bread formulation, the prepared aqueous cladodes extract solutions were kept refrigerated. Crude protein, lipids, ash, total carbohydrates, and crude fiber contents of the extracts were measured according to the AOAC methods [12]. pH values were measured using a pH meter (Hanna instruments, serial number 482002, The UK), total soluble solids using a refractometer, total phenolic content and tannins were measured according to [13] and [12] methods, respectively. The total chlorophyll content of the extract was measured spectrophotometrically as described by [14].

2.2 Chemical analysis of wheat flour

Wheat flour used to prepare pan bread was commercially produced and purchased from a local mill. The moisture (ICC standard No. 110/1), ash (ICC standard No. 104/1), protein (ICC standard No. 167), gluten index, and wet and dry gluten contents (ICC standard No. 137) were measured [15].

2.3 Rheology measurements

The rheological characteristics of dough kneaded with the prepared three aqueous cactus cladodes extract solutions of 5%, 7.5%, and 10% were measured and compared to dough kneaded with deionized distill water (D.D. W) using a Brabender Farinograph-AT and Extensograph Brabender-E according to ICC standard methods No. 115/1 and No. 114/1, respectively [15].

2.4 Bread-making and quality measurements

A straight dough bread preparation was conducted according to the AACC [16], 100% wheat flour, 6% sugar, 2% sunflower oil, 1% compressed yeast (Uniferm GmbH and Co. KG), and 0.5% salt were the ingredients in the regular bread recipe. The control treatment was prepared by kneading the dry components with D.D. W, while the dry components of three other bread treatments were kneaded with the aqueous cladodes extracts solutions of 5%, 7.5%, and 10% according to the results of the farinograph for each treatment. For initial fermentation, the dough was placed in a greased fermentation bowl then in a fermentation cabinet of 80–85% relative humidity (RH) and 38–40 °C temperature for 30 min. The dough was then divided into 400-g pieces, formed, and placed in oiled baking tins to proof for 60 min at a temperature of 38–40 °C and RH of 80–85%. The dough was baked at 180 °C for 20 min in a preheated Matador multideck oven (Werner and Pfleiderer Lebensmitteltechnik GmbH), then the bread was cooled at room temperature before analyses.

Bread loaf-specific volume (cm^3/g) was measured according to the AACC [16] method number 10-05.01. The specific volume of each loaf was calculated by dividing the volume of the loaf (cm^3) by its weight (g).

The *L**, *a**, and *b** color values of loaf crust and crumb for each treatment were measured using a Minolta ChromaMeter (CR-410, Minolta, Konica, Japan) according to the method described by [17].

Twenty-two qualified panelists, from the staff of Department of Nutrition and Food Processing, Faculty of Agriculture, Al-Balqa, Applied University, Irbid, Jordan, were used to evaluate the sensory attributes of bread treatments. They were academic, technicians, and postgraduate students having good experience in sensory evaluation. Loaf volume, appearance, crust color, crumb color, crust uniformity, crumb uniformity, texture, taste, and overall acceptability were evaluated using the 9-point hedonic scale [18].

2.5 Statistical analysis

Analysis of variance (ANOVA) was carried out on data using SAS software version 9.1 [19]. The probability between treatments of a level of 5% was calculated based on the least significant differences (LSD).

3 Results and discussion

3.1 Chemical analysis of cladodes powder and its prepared aqueous extracts

Chemical composition including protein, lipids, ash, total carbohydrates, crude fiber, total soluble solids, pH value, total polyphenols (mg gallic acid eq/100 ml extract solution), tannins (mg/100 ml extract solution), and total chlorophyll (mg/100 ml extract solution) of cladodes extracts solutions are presented in Table 1. As the cladodes extract concentration increased from 5 to 10%; chemical parameters were significantly ($P < 0.05$) increased, except the pH values that decreased with the increase in the cladodes extract concentration. The decrease in pH was attributed to the increased extractable organic acid with the increase in cladodes extract concentration.

Table 1 Characterization of cactus cladodes extract solutions

Extract concentration (%)	T.S.S%	pH	Protein%	Lipids%	Ash%	Total CHO%	Crude fiber%	Total polyphenols (mg gallic acid eq/100 ml extract solution)	Tannins (mg/100 ml extract solution)	Total chlorophyll (mg/100 ml extract solution)
5	2.40 ± 0.03c	5.7 ± 0.0a	0.18 ± 0.06b	0.02 ± 0.00c	0.22 ± 0.08b	1.43 ± 0.20b	0.37 ± 0.07b	2.1 ± 0.2c	0.05 ± 0.00c	1.5 ± 0.4b
7.50	3.00 ± 0.04b	5.5 ± 0.0b	0.24 ± 0.04b	0.04 ± 0.00b	0.35 ± 0.05a	1.82 ± 0.70ab	0.46 ± 0.08b	2.6 ± 0.2b	0.06 ± 0.00b	1.9 ± 0.2ab
10	3.80 ± 0.06a	5.40 ± 0.1b	0.31 ± 0.07a	0.07 ± 0.01a	0.47 ± 0.09a	2.46 ± 0.40a	0.63 ± 0.03a	3.5 ± 0.1a	0.08 ± 0.01a	2.5 ± 0.5a

Results with different letters are significantly ($p < 0.05$) different. Results are means ± SD. n = 3

TSS: Total Soluble Solids; Total CHO: Total Carbohydrates

3.2 Analysis of wheat flour

Moisture, ash (on dry basis), and protein (on dry basis) percentages were 14%, 0.65%, and 11%, respectively, whereas wet gluten, dry gluten, and gluten index were 25.5%, 8.2%, and 97.3%, respectively. The results indicated that this wheat flour is a straight flour, which is commonly used for making of different types of bread [20].

3.3 Rheological measurements of dough

The rheological characteristics of wheat dough treatments are presented in Table 2. Farinograph and extensograph results were significantly (P < 0.05) affected when the dough was kneaded using various aqueous cladodes extracts solutions (i.e., 5, 7.5, and 10%) in comparison to control dough prepared using water. The percentage of water absorption and the degree of softening (DS) of the dough prepared with aqueous cladodes extract increased significantly as the extract concentration increased in comparison to the control treatment.

For dough treatment prepared with 7.5% aqueous cladodes extract, development time (min) and stability (min) were significantly higher, followed by 5% and 10% treatment, whereas control treatment prepared without cladodes extract had the lowest values. Consistency (FU) of dough was significantly higher for treatment with 7.5% aqueous cladodes extract, followed by treatment with 5%, while treatment with 10% extract and control treatment had the lowest consistency values, respectively. Farinograph quality numbers (mm) were significantly higher for treatment with 7.5% extract followed by treatment with 5%, while treatment with 10% and control treatment had the lowest consistency values.

Extensograph analyses of energy (cm^2), resistance (BU), maximum height (BU), ratio R50/E, and ratio maximum Rm/E were significantly higher for treatments kneaded with 7.5% and 5% extract, respectively. While treatment kneaded with 10% extract and control dough had lower extensograph values, respectively. The extensibility (mm) of the control dough, on the other hand, was significantly the highest relative to other treatments kneaded with cladodes extract at all three used levels. These changes in the rheological characteristics may be due to the extractable components of cactus cladode, such as total soluble solids, protein, ash, carbohydrates, crude fiber, polyphenols, tannins, and acids, as shown in Table 1, which were preferable at 7.5% cladodes extract. The increase in water absorption of dough prepared with cladodes extract may be due to the competition between the extractable solids of cladodes and the components of the flour to form the dough, as well as the improvement in the quality of gluten by the components of the extract [21], such as the extracted proteins, polyphenols, and tannins. Carbohydrates were the most abundant portion of cladodes extract, followed by minerals and protein; they could affect dough water absorption because they have different tendencies to absorb water [22].

Polyphenols and tannins have been found to improve the properties of gluten and may be used as natural wheat flour enhancers. Polyphenols, as antioxidants, generally reduce the gluten disulfide cross-linkages, thereby, decreasing gluten strength and the size of network-forming polymeric proteins. On the other hand, by forming extensive hydrogen bonds and hydrophobic interactions, tannins, the high molecular weight polyphenols, can increase the protein matrix density and gluten strength, which could mitigate the antioxidant effect of other polyphenols through cross-linked gluten [23]. The incorporation of polyphenols or polyphenol-rich food by-products was reported to improve their dough and baked products' functional properties [24, 25].

Another aspect that could lead to changes in the rheological properties of wheat dough kneaded with extracts of cladodes is the extractable organic acids. Table 1 indicated a decrease in pH values as the concentration of extracts

Table 2 Farinograph measurements of treatments containing various ratios (i.e., 5, 7.5 and 10%) of cactus cladodes extract

Treatments	Water absorption (%)	Development time (min)	Stability (min)	DS (FU)	DS (ICC) (FU)	FQN (mm)
Control	56.2 ± 0.2^{d}	5:12 ± 0.04^{c}	8:09 ± 0.00^{c}	20.0 ± 0.7^{d}	74 ± 1^{d}	92 ± 1^{c}
5%	57.1 ± 0.3^{c}	5:55 ± 0.06^{b}	8:40 ± 0.00^{b}	25.0 ± 0.5^{c}	92 ± 2^{c}	98 ± 2^{b}
7.5%	57.9 ± 0.2^{b}	6:37 ± 0.05^{a}	9:55 ± 0.01^{a}	30.0 ± 0.9^{b}	112 ± 2^{b}	112 ± 2^{a}
10%	60.2 ± 0.4^{a}	5:53 ± 0.07^{b}	8:34 ± 0.01^{b}	36.0 ± 0.8^{a}	117 ± 4^{a}	94 ± 2^{c}

Results with different letters are significantly ($p < 0.05$) different. Results are means ± *SD*. n = 3

Fig. 1 Bread-specific volume (cm^3/g) index made with cladodes extracts

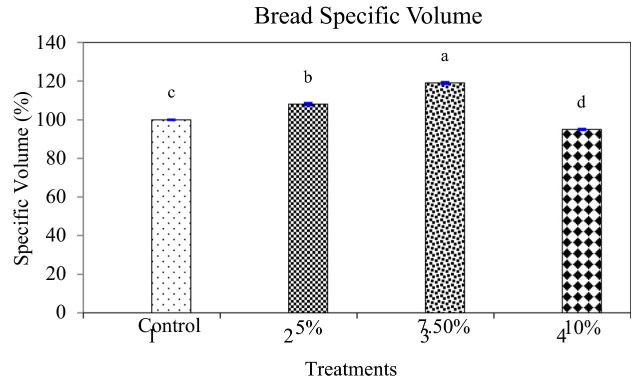

Table 3 Extensograph measurements after135 min. of treatments containing various ratios (i.e., 5, 7.5 and 10%) of cactus cladodes extract

Treatments	Energy (cm^2)	Resistance R50 (BU)	Extensibility E (mm)	Max height Rm (BU)	Ratio R50/E	Ratio max Rm/E
Control	60 ± 1^d	236 ± 2^d	150 ± 1^a	280 ± 3^d	1.57 ± 0.01^d	1.87 ± 0.02^d
5%	73 ± 2^b	356 ± 3^b	133 ± 1^b	396 ± 3^b	2.68 ± 0.03^b	2.97 ± 0.04^b
7.5%	77 ± 2^a	364 ± 3^a	134 ± 1^b	426 ± 3^a	2.73 ± 0.07^a	3.2 ± 0.08^a
10%	68 ± 2^c	336 ± 3^c	135 ± 1^b	365 ± 3^c	2.51 ± 0.05^c	2.72 ± 0.06^c

Results with different letters are significantly ($p < 0.05$) different. Results are means ± *SD*. n = 3

increased from 5 to 10%, which act as reducing agents. The pH and acidity of cactus cladodes were related mainly to malic acid, followed by citric acid, and to a lesser extent ascorbic acid, oxalic acid, and other many organic acids [26].

Compared to control dough and those prepared with 5% and 7.5% extracts of cladodes, the preparation of wheat dough with 10% aqueous cladodes extract caused a significant increase in water absorption percentage, compared to other dough. This might be the reason for the dough's rheological properties drawback since high-water binding can cause undesirable rheological changes to the wheat dough [26]. The increase in extractable carbohydrates, ash, and fibers supports this finding and could also contribute to this effect. In this regard, it was reported that the type and concentration of the organic acids added to wheat flour play a role in influencing dough and baked products' rheological and functional properties. Malic acid, for instance, had no major improvements in dough stability, while citric acid can result in a decrease in mixing tolerance. On the other hand, tannic acid results in an increase in dough mixing tolerance [22]. However, it is worth indicating that the effect of the addition of various organic acids on dough rheology can be influenced by the wheat cultivar type and dough components such as salt concentration [27].

3.4 Bread quality characteristics

The volume of bread, as one of the most significant physical properties of bread, was influenced by the extracts of cladodes (Fig. 1). For treatment formulated with 7.5% aqueous cladodes extract, the highest specific bread volume index significantly ($P < 0.05$) increased by 19% points followed by bread treatment formulated with 5% aqueous cladodes extract that was increased by 8% points compared to control treatment. This increase in bread volume could be due to the enhancements in dough strength, gluten network stability, fermentation properties, and gas retention capacity acquired by the components of the cladodes extract. Our results were in agreement with [27] who reported an increase in bread volume with the increase in dough strength and gluten network formation. Our results were parallel to the rheological results shown in Tables 2 and 3, indicating that treatments with 5% and 7.5% aqueous cladodes extract can improve bread volume.

Bread treatment formulated with 10% cladode extract, on the other hand, had the lowest specific volume index with a 5% points decrease compared to the control. The decrease in bread volume was attributed to the increased water absorption of the dough when using the 10% cladodes extract resulting in the decrease in bread volume. These findings are in agreement with [28] who reported an increase in bread-specific volume of flat bread when using cladodes flour in ratios of 2.5 and 7.5% but a decrease in flat bread volume when using 10% cladodes flour. [8] used the aqueous extract of

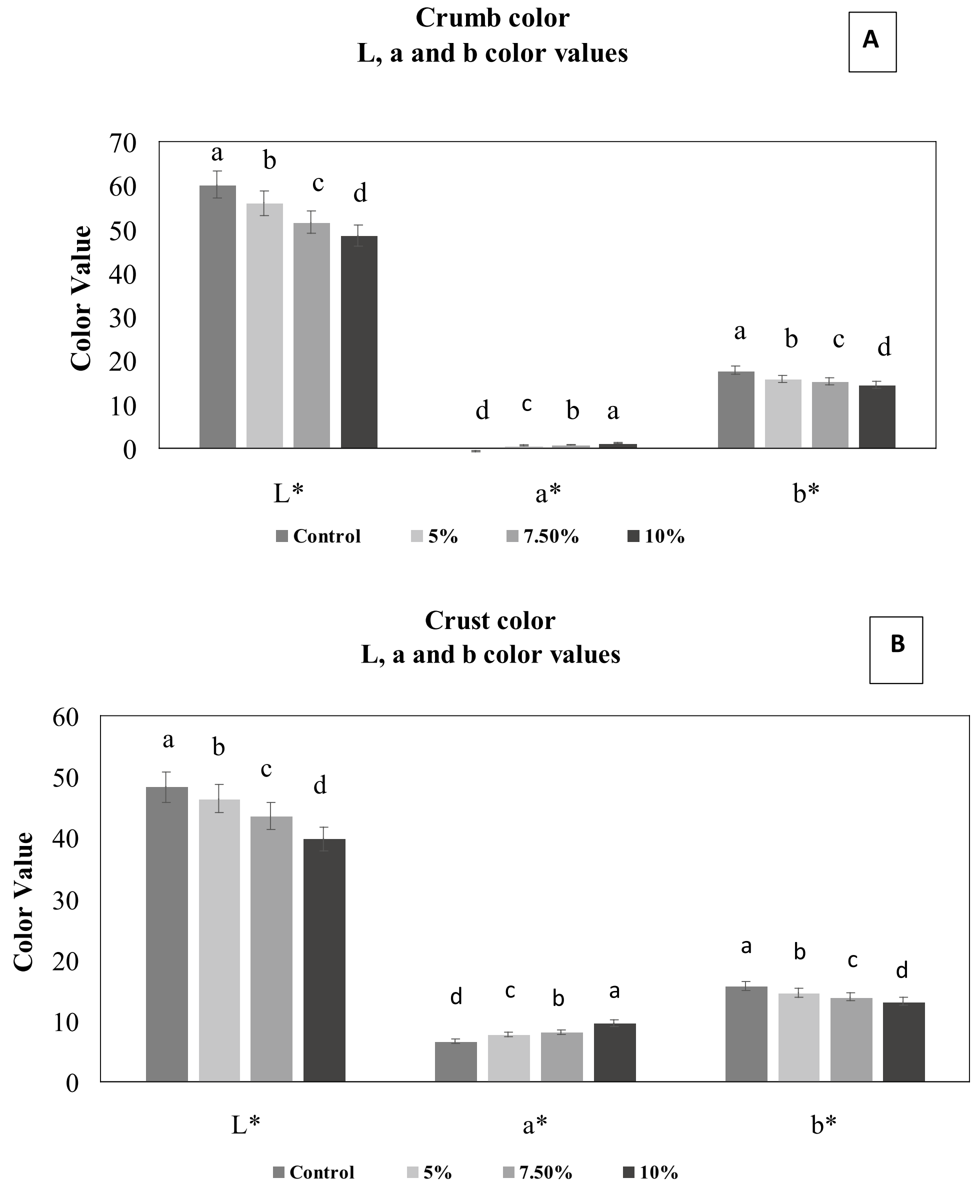

Fig. 2 Color characteristics (L, a, and b) of bread crumb (**A**) and crust (**B**) made with various concentrations of cladodes extracts in the dough

plant powder instead of the powder itself, to improve the volume of pan bread since it is found that the incorporation of plant powders with wheat flour might result in a decrease in pan bread-specific volume index due to dilution of gluten.

The lightness (*L**), redness (*a**), and yellowness (*b**) color values of both crust and crumb at all three extract concentrations used were influenced by the making of pan bread with the aqueous cladodes extract (Fig. 2). As the cladodes extract concentration increased from 5 to 10%, lightness and yellowness for both crust and crumb were significantly ($P < 0.05$) decreased. Regarding *a** color values, a significant increase in redness of bread crust color formulated with cladodes extracts was measured, while a significant measured decrease in crumb color was moved to green color. Our results coincide with those obtained by [28] who substituted wheat flour with cladodes powder at 2.5% to 10% in the formulation of flatbread. [14] also reported similar trends for a cake made by incorporation of cladodes powder at 5% to 20% and [29] for biscuits formulated with cladodes flour at 25% to 100% compared to control treatment from wheat flour. The authors attributed these changes in the color to the increase in Maillard reaction and the richness of cladodes powder in chlorophyll and other pigments that were more affected as the concentration of used cladodes increased, as shown in our results in Table 1.

Organoleptic analysis of pan bread treatments, as shown in Table 4, indicated that the sensory preferences of pan bread were influenced by cladodes extracts at the three levels used (i.e., 5%, 7.5%, and 10%). The same pattern was followed by loaf volume, appearance, crust color, crust uniformity, crumb uniformity, texture, and overall acceptability. Pan

Table 4 Sensory characteristics (i.e., overall acceptability, loaf volume, appearance, crust and crumb color and uniformity, texture and overall taste liking) of bread made using various concentrations (i.e., 5, 7.5, and 10%) of aqueous cactus powder extract

Characteristics[a]	Control (0%)	5%	7.5%	10%
Loaf volume	5.2 ± 0.22^{c}	6.5 ± 0.12^{b}	7.4 ± 0.17^{a}	4.3 ± 0.15^{d}
Appearance	6.5 ± 0.1^{c}	7.1 ± 0.13^{b}	7.9 ± 0.14^{a}	5.6 ± 0.19^{d}
Color				
Crust	6.7 ± 0.21^{c}	7.8 ± 0.22^{b}	8.5 ± 0.25^{a}	5.8 ± 0.18^{d}
Crumb	8.1 ± 0.24^{a}	6.0 ± 0.23^{b}	5.8 ± 0.19^{b}	4.7 ± 0.21^{c}
Uniformity				
Crust	5.3 ± 0.16^{d}	7.6 ± 0.11^{b}	8.4 ± 0.16^{a}	6.2 ± 0.15^{c}
Crumb	6.3 ± 0.32^{c}	7.4 ± 0.24^{b}	8.5 ± 0.28^{a}	5.3 ± 0.31^{d}
Overall acceptability	6.3 ± 0.18^{c}	7.3 ± 0.12^{b}	8.2 ± 0.1^{a}	5.2 ± 0.13^{d}
Overall texture	4.5 ± 0.21^{d}	7.3 ± 0.25^{b}	8.3 ± 0.19^{a}	5.4 ± 0.23^{c}
Overall taste liking	6.4 ± 0.17^{b}	7.4 ± 0.15^{a}	7.6 ± 0.19^{a}	5.4 ± 0.11^{c}

[a]Values of the same sensory characteristics (raw) having different letters are significantly ($P < 0.05$) different according to LSD

bread treatment formulated with 7.5% cladodes extract had significantly ($P < 0.05$) greater acceptability (i.e., like moderately and like very much) followed by the bread of the 5% cladodes extract having a preferences score ranging from like slightly to like moderately. Bread treatment formulated with 10% cladodes extract had the lowest preferences in the range of "dislike slightly" to "neither like nor dislike". The increase in bread volume treated with cladodes extracts could positively affect the preferences of loaf volume and appearance, which were the greatest in the 5% and 7.5% treatments and lowest in the 10% treatment (Fig. 1). Bread taste also enhanced with 5% and 7.5% extract, but significantly ($P < 0.05$) decreased for treatment with 10% extract which could be attributed to the strong taste and aroma of the cladodes at this level. Results were attributed to the improvement of crust redness (Fig. 2B) of bread formulated with 5% and 7.5% extracts, which could be due to the Maillard reaction. The increased ratio of cladodes extract (i.e., 10%) was believed to acquire further darkening resulting in a negative preference for pan bread.

Crumb color preference was the highest in the control bread treatment without cladodes extract and evaluated as "like very much", whereas the other three bread treatments formulated with cladodes extracts had the lowest color preferences. Results were attributed to the increased green color of bread crumbs (Fig. 2A) provided by the chlorophyll pigment of cladodes (Table 1).

Finally, overall acceptability was parallel with all those sensory preferences, as well as some pan bread physicochemical characteristics. The use of aqueous sumac extract in pan bread preparation at concentrations of 0.5% to 5% improved all sensory preferences except for crumb color [8].

4 Conclusions

The integration of cladode extract at concentrations ranging from 5% to 7.5% resulted in enhanced dough characteristics, rendering it more elastic, extensible, and superior in water retention. These enhancements culminated in improved attributes of the bread, characterized by increased volume, more aesthetically pleasing crust coloration, a softer crumb texture, and a more favorable flavor profile in comparison to bread prepared through conventional water kneading. The findings indicate that cladode extract may function as a natural substitute for synthetic additives, thereby enhancing the structural integrity, texture, and sensory properties of bread.

In addition to the physical and sensory enhancements, cladode extract presents prospective nutritional benefits. It is antioxidants, dietary fibers, and essential minerals contents play a vital role in enhancing the nutritional composition of the bread. This aligns with the growing consumer inclination towards functional foods that integrate natural, health-promoting ingredients, thereby augmenting the value of bread products that cater to clean-label and health-oriented market preferences.

The principal outcomes of the study encompass improved rheological properties that facilitate dough manipulation and a more robust bread structure. Bread formulated with cladode extract exhibited favorable sensory characteristics, including superior volume, enhanced crust coloration, and increased crumb softness.

Subsequent research endeavors may investigate a wider spectrum of extract concentrations to ascertain the optimal equilibrium between sensory and nutritional advantages. An exploration into the capacity of cladode extract to prolong the shelf life of bread by mitigating mold proliferation could confer substantial benefits. Broader applications within various bakery products, such as gluten-free bread, pastries, and cookies, could further demonstrate its adaptability.

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Author contributions KA-M did study conception and design, acquisition of data, analysis and interpretation of data, and drafting of manuscript. MS did study conception and design, drafting of manuscript and critical revision. NAS did drafting of manuscript and critical revision.

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Data availability Data is provided within the manuscript.

Declarations

Ethics approval and consent to participate Plant identification was done by Prof. Jalal Al-tabal (jaltabbal@bau.edu.jo), and the experimental protocols were approved by the Al-Balqa Applied University Research. Voucher specimens were kept at the Herbarium of the Department of Plant Production and Protection, Faculty of Agriculture, Al-Balqa Applied University, Jordan, with ID Number 79-10-548-009.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests.

Human ethics The study was approved by the Ethical Committee, The Univesity of Jordan 8180371-1/2024. Human testing was conducted after oral conscience was permitted from each participant. The study protocol was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

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