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Production of novel low-sodium salty biscuits for DASH diet by using iceplant (*Membryanthemum crystallinum*) powder

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Abstract

This study is the first to investigate iceplant powder as a salt substitute in salty biscuits. Salty biscuits were prepared by substituting salt with different amounts of iceplant powder (ranging from 1.2 to 6%) and evaluated their physical, sensory, chemical, and antioxidant properties. The initial amount of salt was replaced, and flour inclusion was adjusted to the original formulation. Using different amounts of iceplant powder during salty biscuit preparation caused several variations in technological (increased saltiness, width, and spread ratio and decreased weight and thickness), textural (decreased hardness and fracturability values), and color properties (decreased L* and a* and increased b*). Salty biscuits with 3% iceplant powder were the most widely accepted compared to others that contained iceplant powder. When salt was replaced with 3% iceplant powder, the moisture content increased (from 3.25 to 3.3%), and so did the crude protein (from 8.95 to 9.37%), ether extract (from 10.47 to 10.53%), crude fiber (from 0.51 to 1.06%), energy value (from 431.43 to 433.33 kcal/100 g), total carbohydrates (from 75.35 to 75.25%), total phenolics (from 0.07 to 9.31 mg GAE/g), and total flavonoids (from 0.08 to 11.69 mg QE/g). Salty biscuits with 3% iceplant powder had high antioxidant activity around 1.33 and 1.21 times greater than control by using ABST and DPPH methods, respectively. However, replacing 1.2% NaCl with 1.2 or 3% iceplant powder caused a reduction in the sodium content, 85.61 and 64.2%, respectively. Therefore, iceplant powder represents a promising salt replacer for enhancing food products, particularly for those seeking lower sodium options.

Keywords: antioxidant activity; DPPH; iceplant powder; salty biscuits; sodium reduction; texture

Introduction

Biscuits are one of the most commonly sold bakery items in the world. It is popular as a snack due to its range of flavors and shapes. The world market for biscuits was valued at USD 76.385 billion by the end of 2017 and is projected to increase at compound yearly growth rates of 3.7 and 5.08%, reaching 121 billion dollars by 2021 and 164 billion dollars by 2024, respectively (Goubgou *et al.*, 2021). According to Canalis *et al.* (2017), around 13 kg of biscuits are consumed per person annually worldwide. One of the most popular varieties of biscuits is the salty kind, which has a high sodium chloride content and is regarded as lacking in essential nutrients. Sodium chloride (NaCl) is a necessary element in the production of food products. It imparts unique physical and chemical bonding during baking and helps determine the product's sensory qualities (He *et al.,* 2021). Processed foods account for approximately 77% of total sodium intake (Dötsch *et al.,* 2009). This is attributed to their high salt content (e.g., processed meats, ready meals, and salty biscuits or snacks) or their frequent high consumption (e.g., bread, processed grain products, and biscuits) (Ni Mhurchu *et al.,* 2011). Consuming a lot of salt elevates blood pressure, which in turn boosts the risk of heart attacks, strokes, and cardiovascular disease (Hunter *et al.,* 2022). According to the recent recommendations from the World Health Organization (WHO), people should not exceed 2 g of sodium (Na, 23 g/mol) per day, which is equivalent to 5 g of salt (NaCl, 58.5 g/mol) (WHO, 2022). However, the mean intake in Egypt is above the recommended limit of 9–12 g daily (Khalil and Azqul, 2018). In this regard, the WHO has established a global goal of reducing salt intake by 30% in 2025 to lessen the effect of health disorders linked to excessive sodium consumption (WHO, 2015). This is consistent with the Dietary Approach to Stop Hypertension (DASH), a dietary program that helps lower high blood pressure. Hence, alternative natural sources of table salt are required. Prior investigations have stated that halophytes, especially Salicronia, are promising strategies to reduce or replace salt in food products (Ferreira *et al.,* 2022; Lim *et al.,* 2015; Lopes *et al.,* 2017). Halophytes, plants that have evolved to survive in saline environments, are extremely high in nutrients, including amino acids, fatty acids, and antioxidants, and numerous species are traditionally utilized as vegetables, herbs, fodder, and feed (Gouda and Elsebaie, 2016). The halophytic plant *Mesembryanthemum crystallinum*, also referred to as the "Iceplant," is a member of the Aizoaceae family and is very resistant to stress, salt, drought, and extremely high temperatures (Essa and Elsebaie, 2018). The aerial parts of the iceplant include minerals, inositol, beta-carotene, and other nutrients that are beneficial to human health (Lee *et al.,* 2015). The iceplant has been shown to have a variety of physiological activities, including antioxidant capabilities, hypoglycemic action, antimicrobial effects, radical scavenging activity, memory-improving activity, and anti-nootropic and antihypertensive properties (Kang and Joo, 2023). It has long been used in Africa to replenish salt and water and avoid dehydration. In Europe and Japan, it has been emphasized as a useful vegetable with savory and salty flavors that have been used for decades in a variety of dishes (Bazihizina *et al.,* 2024). Salt crystals are also dispersed throughout the plant's surface. Thus, the plant's capacity for salt accumulation might be advantageous for bioremediation (Renshaw, 2021). It is important to remember that iceplants are facultative halophytes, meaning they can adjust to their physiological surroundings and react to high salinity (He *et al.,* 2022). The use of iceplant powder in food preparation as a salt substitute is undocumented. Hence, this study is the first to work on this point. Thus, the current investigation intends to emphasize the impact of using iceplant powder as a substitute for salt during salty biscuit preparation on their physical, sensory, chemical, and antioxidant properties.

Materials and Methods

Materials

Iceplant (*M. crystallinum*) was harvested in June 2023 when it reached maturity (red color) from areas beside an international coastal road close to El-Brolos Lake in Kafr El-Shiekh, Egypt (32°34'N, 31°14'E). The plant was identified by the department of Plant Botany, Faculty of Agriculture, Kafrelshiekh University. All ingredients used for salty biscuits (wheat flour (80%), olive oil, salt, and raising agent) were bought at Fathalla Market in Gharbia, Governorate of Egypt. All reagents (HPLC-grade) were obtained from Sigma-Aldrich Company (MO, USA).

Methods

Iceplant powder preparation

Iceplant powder was produced using the procedure outlined by Essa and Elsebaie (2018). After washing the aerial parts of the gathered iceplant with distilled water and wiping off any extra water using a white towel, they were left to sun dry for 14 days at 25 ± 5°C in the shade. After that, it was placed in an oven at 45°C for 12 h to get crispy dry. It was then ground into a powder using an electric grinder (Moulinex MFP626, 220 V, 50–60 Hz, 1000 W, 250 mL, France), and the fine powder was obtained by sieving it through a 100-mesh screen. The powder was subsequently stored in an airtight container for later use.

Salty biscuits preparation

Samples of salty biscuits were made using the formulations (w/w) listed in Table 1. Dried iceplant powder percentages ranging from 1.2 to 6% were examined after replacing the original salt amount and modifying the flour integration (Table 1). Salty biscuits were made using the method described by Schouten *et al.* (2023). The dough was prepared by combining flour, salt, and raising agent in a kitchen mixer (TOUCH764, Banha, Egypt) and mixing at Level 3 for 15 s. Next, the liquid components (water and oil) were incorporated, and the mixture was combined at the fourth speed for 1.30 min. The doughs were then taken out of the mixer and processed using hand for a minute to create homogenous mixes. Before shaping, the mixtures were left to rest for 20 min at 4°C in the refrigerator. After resting, the doughs were

Table 1. Salty biscuits formulations (%, w/w).

Ingredients	Types of salty biscuits						
	Control	1.2% Iceplant powder	2% Iceplant powder	3% Iceplant powder	4% Iceplant powder	5% Iceplant powder	6% Iceplant powder
Wheat flour	65	65	64.2	63.2	62.2	61.2	60.2
Water	26	26	26	26	26	26	26
Olive oil	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Salt	1.2	–	–	–	–	–	–
Raising agent	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Iceplant powder	–	1.2	2	3	4	5	6

manually kneaded and moulded into a round form with a plastic mould. They were subsequently set in the baking trays and baked for 20 min at 170°C in a baking oven with thermostatic control. The biscuits were then cooled to room temperature (25 ± 3°C) and wrapped in polyethylene bags before examination.

Water activity determination

Water activity (aw) was determined using a Hygro Palm-HP23-AW-A thermohygrometer (Bassersdorf, Switzerland). Analyses were repeated in triplicate.

pH measurement

A PH8500-HF portable pH meter (Guangzhou, China) was used to measure the pH of baked salty biscuits. A mixture of 3 g of sample and 6 mL of distilled water was vortexed for 30 s, and the pH of the liquid fraction was determined. For every sample, six replicates were assessed.

Salinity measurement

A Pocket Pal-salt Probe 4222 JP salinity meter (Changsha, China) was used to measure the salinity. Four grams of the sample was weighed and mixed with 40 mL of distilled water continuously for 5 min. Three measurements were made to get the average value.

Salty biscuits dimensions

The AACC Method 10-31.03 (AACC, 1999) was used to measure the weight, breadth, and thickness (height) of the biscuits. Eight biscuits were weighed and measured for overall diameter and height (at the top center of each biscuit). The findings were presented for one biscuit. The following calculations, as per Sai Manohar and Haridas Rao (1999), were used to calculate the density, spread ratio, and spread factor of the biscuits.

$$\text{Spread ratio} = \frac{\text{Biscuit diameter}}{\text{Biscuit thickness}} \quad (1)$$

$$\text{Spread Factor} = \frac{\text{Spread ratio of salty biscuits with iceplant added}}{\text{Spread ratio of the control salty biscuit}} \quad (2)$$

$$\text{Density}(\text{g/cm}^3) = \frac{\text{Salty biscuits weight}}{\text{Salty biscuits volume}} \quad (3)$$

Texture properties

The TA-HDi600 texture analyzer (Surrey, UK) was used to analyze the texture of baked salty biscuits at ambient temperature. It was outfitted with a 25 kg load cell, a horizontal stainless-steel instrument, and a three-point bend ring. The precise speeds for the test were 1 mm/s, 5 mm/s for pretest, and 10 mm/s for the post-test. The two beams were 20 mm apart, while the probe distance was 5 mm. Fracture hardness (N), which is derived from the maximum force values, and fracturability (1/mm), which is the inverse of the distance (mm) between the origin and the biscuit breakage point, were among the recorded characteristics (Schouten *et al.*, 2023). For every sample, 10 replicates were assessed.

Color of salty biscuits

The approach by Kumar *et al.* (2023) was followed in measuring the color of the salty biscuit samples using the Minolta CR-5 (Minolta, Tokyo, Japan) colorimeter with standard illuminant D65 and a viewing angle of 10°. The following characteristics were measured: b^* ($b^* > 0$: yellow, $b^* < 0$: blue), a^* ($a^* < 0$: green, $a^* > 0$: red), and L^* ($L^* = 100$ white, $L^* = 0$ black). A minimum of five were taken.

Sensory evaluation

The color, texture, taste, odor, and the overall acceptance of the salty biscuit samples were evaluated. The salty biscuits were prepared and kept in a vacuum desiccator within polythene zip-lock bags until the sensory assessment was completed. The selection process for the untrained panelists adhered to the methodology by Sulieman *et al.* (2019). Twenty panelists, ranging in age from 19 to 37 years old, were given seven biscuit samples, six of which had iceplant powder and one of which was a control. The samples were placed on a plate along with a glass of water, a pen, and a sensory score sheet. The sensory evaluation was conducted in the laboratory

2 h after a midday meal at ambient temperature (25 ± 3°C). The samples were given to the panelists in a random order and tagged with random three-digit codes. To prevent taste bias, the panelists were advised to sip water and clean their mouths before and after tasting each item. The panelists required 25 min to finish the assessment procedure, which involved asking them to rate the sample and allowing them to express their choice on a 9-point hedonic scale from 1 (strongly dislike) to 9 (definitely like).

Proximate and calorie value determination

The A.O.A.C (2010) techniques were used to determine the moisture, proteins (N × 6.25), fat, crude fiber, ash, and total carbohydrate contents of iceplant powder and salty biscuits. Elsebaie *et al*. (2022) determined the calorie content using the following calculations: 9 kcal/g fat, 4 kcal/g protein, and 4 kcal/g carbohydrate.

Quantification of total phenolics and flavonoid contents

The powder of iceplant or salty biscuits (20 g) was extracted using 100 mL ethanol (80%). The extracts were then vacuum-concentrated at 40°C after being filtered using Whatman filter paper (No 4 Chr, UK). The technique outlined by Waterhouse (2002) was used to estimate the total phenolic contents of the extracts as mg gallic acid equivalent (GAE)/g of extract. The flavonoids were measured following the recommendations of Zhishen *et al*. (1999), and the results were expressed as milligram of quercetin equivalent (QE) per gram of extract.

DPPH radical scavenging activity

The effect of DPPH radical scavenging was investigated using the methodology described by Fki *et al.* (2005). Hundred microliters of each extract were combined with 4 mL of DPPH 0.004% methanol solution. The absorbance at 517 nm was measured compared with the blank following 30 min incubation at room temperature. To calculate the proportion of DPPH inhibition (%), the following formula was applied.

$$\text{Inhibition }\% = \frac{\text{Blank absorbance} - \text{Sample absorbance}}{\text{Blank absorbance}} \times 100 \quad (4)$$

2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonate) ($ABTS^+$) activity

The antioxidant activity was measured using the previously published ABTS+ method (Sayah *et al.,* 2017). Phosphate buffer solution with a pH of 7.4 was combined with a 5 mM ABTS solution. After combining the ABTS stock solution with MnO_2, the resultant ABTS radical cation ($ABTS^+$) was filtered via a polyvinylidene fluoride membrane. The absorbance of the solution was measured using a 1 cm cuvette after diluting with PBS (pH 7.4), brought to equilibrium at 30°C, and stored at 20°C until needed. At 734 nm, the absorption was at its peak. In an Eppendorf tube, each extract was mixed with 3 mL of the $ABTS^+$ solution at a volume of 0.05 mL and shaken rapidly. Before measuring the absorbance at 734 nm, the reaction mixture was allowed to remain in the dark at room temperature for 7 min.

$$\text{Inhibition }\% = \frac{\text{Blank absorbance} - \text{Sample absorbance}}{\text{Blank absorbance}} \times 100 \quad (5)$$

Minerals determination

The values of magnesium, iron, manganese, phosphorus, and zinc were determined using an atomic absorption spectrophotometer (Zeiss FMD3, England), whereas the values of potassium, sodium, and calcium were determined using a flame photometer (A.O.A.C, 2010).

NaCl content determination

NaClin biscuits was determined according to Ayed *et al.* (2021).

Statistical analysis

The data obtained were examined using Steel (1980) methodology. When comparing more than two variables, one-way analysis of variance (ANOVA) employing the general linear models (GLM) technique was utilized to search for major effects. P-values < 0.05 indicated statistical significance for differences.

Results and Discussion

Salty biscuits physical and textural properties

Several changes occur in the biscuit dough throughout the baking process. Among the most significant changes are those related to dimension, moisture loss, and the development of flavor and color. The final product dimensions are essential to maintain the quality of baked products (Arepally *et al.,* 2020). Table 2 displays the physical characteristics (water activity, pH, saltiness, technological properties, texture, and color parameters) of salty biscuits prepared using iceplant. Due to the low moisture content of salty biscuits, water activity (aw) is a crucial characteristic that must be considered. Aw has a direct impact on the shelf life, crispiness, and sensory acceptability of these items. Biscuit softening occurs when the "aw" exceeds the critical value of 0.5 (Ayed *et al.,* 2021). There was no significant difference (P < 0.05) in the water activity values of the biscuits prepared with and without iceplant powder. However, there were increasing tendencies when more iceplant powder was added. All aw obtained values were less than the critical aw, which

Table 2. Effect of salt substitution with 0% to 6% iceplant powder on salty biscuits physical and textural properties.

Parameters	Types of salty biscuits						
	control	1.2% Iceplant powder	2% Iceplant powder	3% Iceplant powder	4% Iceplant powder	5% Iceplant powder	6% Iceplant powder
Water activity	0.38 ± 0.02^{a}	0.39 ± 0.01^{a}	0.39 ± 0.01^{a}	0.40 ± 0.02^{a}	0.41 ± 0.03^{a}	0.41 ± 0.02^{a}	0.42 ± 0.01^{a}
pH	6.37 ± 0.01^{a}	6.33 ± 0.03^{a}	6.33 ± 0.05^{a}	6.32 ± 0.02^{a}	6.31 ± 0.04^{a}	6.31 ± 0.02^{a}	6.30 ± 0.01^{a}
Saltiness %	2.47 ± 0.12^{b}	1.37 ± 0.04^{d}	1.77 ± 0.06^{c}	2.43 ± 0.15^{b}	2.64 ± 0.10^{ab}	2.71 ± 0.06^{a}	2.88 ± 0.13^{a}
Weight (g)	4.96 ± 0.11^{a}	4.92 ± 0.10^{a}	4.90 ± 0.11^{a}	4.87 ± 0.13^{ab}	4.82 ± 0.10^{b}	4.78 ± 0.11^{c}	4.72 ± 0.13^{d}
Width (cm)	4.13 ± 0.1^{d}	4.16 ± 0.1^{cd}	4.18 ± 0.1^{c}	4.23 ± 0.2^{c}	4.30 ± 0.1^{b}	4.35 ± 0.2^{a}	4.38 ± 0.2^{a}
Thickness (mm)	4.82 ± 0.31^{a}	4.78 ± 0.28^{a}	4.73 ± 0.17^{a}	4.68 ± 0.30^{ab}	4.61 ± 0.25^{b}	4.56 ± 0.27^{b}	4.38 ± 0.30^{c}
Spread ratio	8.57 ± 0.44^{c}	8.70 ± 0.41^{c}	8.84 ± 0.43^{c}	9.04 ± 0.42^{bc}	9.35 ± 0.37^{b}	9.54 ± 0.29^{a}	10.00 ± 0.35^{a}
Spread Factor	1.00 ± 0.01^{a}	1.02 ± 0.01^{a}	1.03 ± 0.01^{a}	1.05 ± 0.02^{a}	1.09 ± 0.01^{a}	1.11 ± 0.01^{a}	1.17 ± 0.01^{a}
Density (g/cm^3)	0.60 ± 0.03^{a}	0.59 ± 0.03^{a}	0.59 ± 0.02^{a}	0.58 ± 0.02^{a}	0.57 ± 0.02^{a}	0.55 ± 0.03^{a}	0.56 ± 0.03^{a}
Texture parameters							
Hardness (N)	14.81 ± 0.91^{a}	14.77 ± 1.03^{a}	14.36 ± 0.95^{b}	14.03 ± 1.07^{b}	13.95 ± 0.87^{b}	11.87 ± 0.99^{c}	11.02 ± 1.0^{d}
Fracturability (mm)	4.70 ± 0.28^{a}	4.68 ± 0.39^{a}	4.61 ± 0.31^{a}	4.55 ± 0.30^{ab}	4.50 ± 0.25^{b}	3.82 ± 0.33^{d}	3.61 ± 0.31^{d}
Colour parameters							
L	64.21 ± 0.7^{a}	61.19 ± 0.7^{b}	59.31 ± 0.74^{c}	56.54 ± 0.75^{d}	54.08 ± 0.72^{e}	51.49 ± 0.81^{f}	47.06 ± 0.6^{g}
a	7.51 ± 0.28^{a}	5.32 ± 0.10^{b}	4.07 ± 0.29^{c}	2.45 ± 0.12^{d}	1.56 ± 0.16^{e}	−0.98 ± 0.03^{f}	−3.11 ± 0.1^{g}
b	28.97 ± 0.4^{g}	32.54 ± 0.3^{f}	34.72 ± 0.4^{e}	37.11 ± 0.2^{d}	40.33 ± 0.4^{c}	42.95 ± 0.3^{b}	46.20 ± 0.3^{a}

Data are presented as means ± SD.
Values followed by the same letter in each row are not significantly different at P < 0.05.

had no detrimental influence on the product's crispiness or sensory acceptability. The pH findings did not reveal any significant variations (P < 0.05) between the control and the other salty biscuit samples with iceplant powder. Furthermore, the control sample of salty biscuits had a pH of 6.37, which was higher than other samples containing iceplant powder, which had pH values ranging from 6.30 to 6.33. Based on the findings of the saltiness analysis, the saltiness value of the salty biscuits with 1.2% or 2% iceplant powder was significantly lower than that of the control group. Conversely, the saltiness value of the salty biscuits containing iceplant powder ranged from 4 to 6%, which was substantially greater (P < 0.05) than that of the control sample. There is no difference (P < 0.05) in the saltiness values between the salted biscuits made with 3% iceplant powder and the control sample. The thickness of the salty biscuits is due to changes in the biscuit structure due to the gluten heat-induced denaturation, in addition to the expansion occurring in the dough as a result of both ra-ising materials and steam (Zheng *et al.,* 2020). According to the results tabulated in Table 2, all salty biscuits prepared using iceplant powder had lower thickness values compared to the controls. In addition, the decrease in the thickness values of salty biscuits increased as a function of the increased amount of iceplant powder added. These results may be because the gluten matrix has been diminished by replacing wheat flour with iceplant powder in salty biscuits (Ramashia *et al.,* 2021). Throughout the biscuit-making steps, the sheeting places tremendous stress on the dough, and the elastic constituents in the dough result in the gradual constriction of the sheet of dough (Bolek, 2020). According to the salty biscuit width data given in the same table, the control sample has the lowest value (4.13 cm), and the width findings show that the width of the salty biscuits increased as the amount of iceplant powder increased (P < 0.05). The obtained results can be explained according to the fact that the elasticity of the dough reduced with an increased amount of iceplant (Lou *et al.,* 2021). In the current investigation, the weight of the biscuits decreased as the added amount of iceplant powder increased (P < 0.05). The reduced thickness of the biscuits due to the diluted gluten network and the dough's viscosity may have resulted in the weight reduction of the salty biscuits made by replacing salt with varying quantities of iceplant powder. When gluten-containing wheat flour is substituted with iceplant powder, the amount of elastic recovery reduces, leading to a reduced contraction in the biscuit dough. Thus, weight and thickness were reduced. The spread ratio is an essential physical characteristic of biscuits. A high spread ratio value was listed as a preferred biscuit quality attribute (Mengeneh and Ariahu, 2022). When iceplant powder was substituted more often, the spread ratio of salty biscuits increased. As with the thickness and weight of salty biscuits, there was no statistically significant difference ($P < 0.05$) in the spread ratio values between the control and salty biscuits that constituted up to 3% of iceplant powder added as a salt substitute. The spread factor measures the diameter and thickness of the iceplant powder–added biscuits compared to the salty biscuit controls. The spread factor values of the salty biscuits prepared using iceplant powder up to 3% as a salt substitute did not differ significantly ($P < 0.05$) from the salty biscuit controls, in line with thickness and spread ratio. Furthermore, there was no noticeable difference ($P < 0.05$) in the density of salty biscuits between samples when iceplant powder was added, and remained almost constant.

One of the crucial and preferred biscuit aspects is its textural quality, which includes hardness and fracturability. The maximum strength needed to shatter a biscuit is known as hardness. Fracturability assesses a product's ability to fight and restore its original condition or shape. It has been noted that the type, amount, and protein content of the flour used can affect the product's hardness and other characteristics, in addition to the baking conditions (Masmoudi *et al.,* 2021). Fracturability was characterized as the resistance to breaking and bending the biscuits. Biscuits with shorter break distances are more fracturable (Principato *et al.,* 2021). All samples of salty biscuits with iceplant powder showed reduced hardness (11.02–14.77 N) compared to the control biscuit (14.81 N) ($P < 0.05$). The only exception was the sample of salty biscuits with 1.2% iceplant powder, which did not vary from the control ($P < 0.05$) (Table 2). The hardness of salty biscuits containing iceplant powder typically reduced as the amount of iceplant powder increased ($P < 0.05$). The fracturability values of salty biscuits that had iceplant powder added as a salt substitute showed a similar pattern. Additionally, the data displayed in the same table demonstrated that compared to the control biscuit (4.70 mm), all salty biscuit samples with iceplant powder had decreased fracturability (3.61–4.68 mm). However, the addition of less than 4% of iceplant powder did not affect the biscuit's fracturability ($P < 0.05$). Consequently, while preparing salty biscuits, using iceplant powder instead of salt produced a softer and less dense texture when compared to the control. Iceplant powder may result in the dilution of the gluten concentration. Furthermore, there was a plausible interaction between wheat protein and iceplant powder. As a result, the dough for salty biscuits lost its strength and elasticity (Lou *et al.,* 2021). Consequently, the resulting salty biscuits lost some of their hardness and fracturability. KC *et al.* (2022) found similar findings when they partially substituted *Moringa* leaf powder with wheat flour.

Table 2 displays the color values of the control and iceplant powder replaced biscuits, given in terms of lightness (L^*), redness to greenness (a^*), and yellowness to blueness (b^*). With the substitution of iceplant powder, there was a minor rise in the b^* value and a modest reduction in the L^* and a^* values. According to the L^* values, which decreased from 64.21 for the control to 47.06 for the 6% iceplant powder–enriched salty biscuits, the addition of iceplant powder resulted in darker salty biscuits. Conversely, adding iceplant powder had a negative impact on the a^* values ($P < 0.05$) of the salty biscuits and increased their greenness. The salty biscuits made with iceplant powder had a^* values ranging from 5.32 to −3.11, which was significantly lower than the control sample (7.51). The lower a^* values of salty biscuits containing iceplant powder may be due to the high chlorophyll content in iceplant. The salty biscuits contained iceplant b^* values that ranged from 32.54 to 46.20, which were significantly ($P < 0.05$) higher than the value of salty biscuit control (28.97). Also, there was a significant ($P < 0.05$) increase in b^*values with increased addition of iceplant powder from 1.2 to 6%. The brown-colored components, such as pheophorbide (Valverde, 2021), are produced during baking due to the degradation of chlorophyll pigments (Benucci *et al.,* 2022). The Maillard reaction is then added to these compounds, which explains the emergence of the yellow–brown coloration when the addition of iceplant powder increased.

Salty biscuits sensory evaluation

Table 3 presents the sensory characteristics of the salty-biscuit samples. The samples of salty biscuits showed substantial variation ($P < 0.05$) in terms of taste, color, odor, texture, and overall acceptance. The amount of iceplant powder greatly affected the taste and color of salty biscuits. All sensory assessment scores were lower for biscuit samples with a larger percentage of iceplant powder (6%). There were no significant differences ($P < 0.05$) in evaluated sensory qualities between control and salty biscuits with 3% iceplant powder. All salty biscuits with iceplant powder were generally accepted, except for those with 6% iceplant powder. Nevertheless, when compared to other salty biscuits that included iceplant powder, the ones with 3% iceplant powder had scores similar to the control and were preferred more. Therefore, only the salty biscuits with 3% iceplant powder incorporation, preferred by the panellists, were subjected to chemical analyses and bioactive component evaluations.

Salty biscuits chemical composition

The approximate chemical composition of salty biscuits containing 3% iceplant powder and iceplant powder itself is shown in Table 4. Based on the given data, iceplant powder has high levels of ash (19.59%), crude

Table 3. Effect of salt substitution with 0% to 6% iceplant powder on the sensory attributes scores of salty biscuits.

Sensory attributes	Types of salty biscuits						
	Control	1.2% Iceplant powder	2% Iceplant powder	3% Iceplant powder	4% Iceplant powder	5% Iceplant powder	6% Iceplant powder
Color	8.2 ± 0.21[a]	8.1 ± 0.33[a]	8.0 ± 0.25[a]	8.0 ± 0.24[a]	7.3 ± 0.19[b]	6.3 ± 0.22[c]	4.2 ± 0.36[d]
Texture	8.5 ± 0.32[a]	8.5 ± 0.24[a]	8.3 ± 0.26[a]	8.1 ± 0.18[a]	7.5 ± 0.33[b]	6.2 ± 0.41[c]	4.9 ± 0.37[d]
Odor	8.3 ± 0.19[a]	8.2 ± 0.23[a]	8.2 ± 0.35[a]	8.2 ± 0.28[a]	8.1 ± 0.30[a]	7 ± 0.29[b]	5.1 ± 0.26[c]
Taste	8.5 ± 0.30[a]	5.3 ± 0.27[d]	6.8 ± 0.31[c]	8.5 ± 0.24[a]	8.4 ± 0.28[a]	7.1 ± 0.25[b]	4.8 ± 0.33[d]
Overall acceptance	8.4 ± 0.24[a]	7.5 ± 0.28[a]	7.8 ± 0.29[a]	8.2 ± 0.36[a]	7.8 ± 0.33[a]	6.7 ± 0.40[b]	4.8 ± 0.22[c]

Data are presented as means ± SD.
Values followed by the same letter in each row are not significantly different at P < 0.05.

Table 4. Proximate chemical composition (%) of control salty biscuits and salty biscuits contained 3% iceplant powder.

	Iceplant powder	Types of salty biscuits	
		Control	3% Iceplant powder
Moisture (%)	11.3 ± 0.77[a]	3.25 ± 0.38[b]	3.3 ± 0.25[b]
Crude protein (%)	21.28 ± 1.17[a]	8.95 ± 0.64[c]	9.37 ± 0.72[b]
Ether extract (%)	2.98 ± 0.41[b]	10.47 ± 1.10[a]	10.53 ± 0.49[a]
Crude fiber (%)	18.46 ± 0.90[a]	0.51 ± 0.05[c]	1.06 ± 0.08[b]
Ash (%)	19.59 ± 0.88[a]	1.98 ± 0.26[b]	1.53 ± 0.15[c]
Total carbohydrates (%)	44.85 ± 1.15[b]	75.35 ± 0.97[a]	75.27 ± 1.04[a]
Caloric values (kcal/100 g)	291.34 ± 2.50[b]	431.43 ± 2.60[a]	433.33 ± 2.31[a]
Total phenol (mg/g)	13.2 ± 1.98[a]	0.07 ± 0.01[c]	9.31 ± 1.17[b]
Total flavonoids (mg/g)	24.5 ± 1.76[a]	0.08 ± 0.01[c]	11.69 ± 1.45[b]

Data are presented as means ± SD.
The difference calculated total carbohydrates.
Values followed by the same letter in each row are not significantly different at P < 0.05.

protein (21.28%), and crude fiber (18.46%). These results were comparable to that of Lian *et al.* (2020). When salt was replaced with 3% iceplant powder, the moisture content increased (from 3.25 to 3.3%), as did the crude protein (from 8.95 to 9.37%), ether extract (from 10.47 to 10.53%), crude fiber (from 0.51 to 1.06%), energy content (from 431.43 to 433.33 kcal/100 g), and total carbohydrates (from 75.35 to 75.25%). Further, data in the same table showed no significant differences (P < 0.05) in the energy, moisture, ether extract, and total carbs between the salty biscuits with 3% iceplant powder and the control. Furthermore, a significant difference (P < 0.05) was observed between the amounts of crude protein, crude fiber, and ash in the control and salty biscuits containing 3% iceplant powder.

The total phenolic and flavonoid contents of the salty biscuit samples and the iceplant powder extract are shown in Table 4. The ice plant powder extract has a high phenolic (13.2 mg GAE/g) and flavonoid content (24.5 mg QE/g), but these values were lower than those found by Alshalmani *et al.* (2020), which is normal for biological materials that vary with all kinds of external effects (climate, soil, etc.), as well as their stage of growth, maturation, and so on. Figure 1 shows that the preparation of salty biscuits using 3% iceplant powder as a salt substitute resulted in a substantial (P < 0.05) increase in the total phenolic (from 0.07 to 9.31 mg GAE/g) and total flavonoid contents (from 0.08 to 11.69 mg QE/g). According to this finding, powdered aubergine is a good antioxidant source and may be a desirable addition to food products.

Figure 1 illustrates the antioxidant activity of the salty biscuits with 3% iceplant powder and the control based on DPPH and ABTS tests. When the amount of iceplant powder in the dough increased, both tests showed a noticeable increase in antioxidant activity. The antioxidant activity for each salty biscuit sample measured by DPPH was lower than ABTS. Our findings are consistent with those of Hassan (2023), who added 5–15%

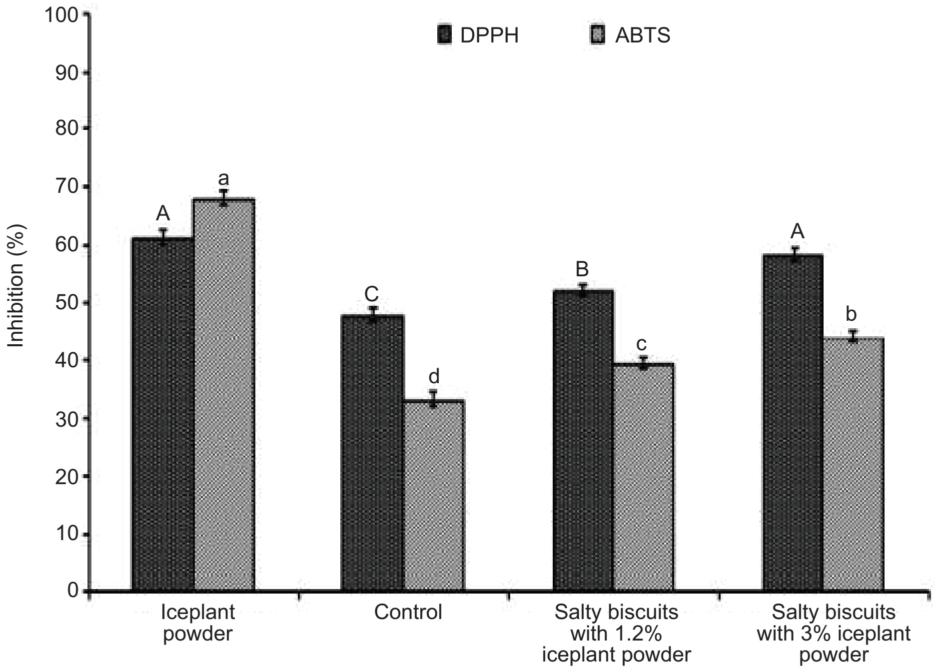

Figure 1. Antioxidant activity of salty biscuits enriched with 1.2 or 3% of iceplant powder extract. Results are expressed as average ± standard deviation. Different uppercase letters correspond to significant differences (P < 0.05) between samples obtained with the DPPH method. Different lowercase letters correspond to significant differences (P < 0.05) between samples obtained with the ABTS method.

extract of sting nettle (*Urtica diocia* L.) leaves to salty biscuits. According to the DPPH and ABTS techniques, the correlation coefficient (R2) between total phenolic and antioxidant activity was 0.969 and 0.986, respectively. This suggests that the antioxidant activity in salty biscuit samples is due to the presence of phenolic components.

Caramelization and the Maillard process produce phenolic components in baked products (Ertugral, 2021). The results showed that both techniques have a high antioxidant capacity for the iceplant powder extract, with 61.4 and 68.1%, respectively, for DPPH and ABTS methods. Results for the ABST technique showed a higher antioxidant capability than the DPPH radical. Incorporating 3% iceplant powder significantly increased antioxidant activity (P < 0.05) in salty biscuits using the DPPH technique (58.34%) compared to the control sample (48.09%). The ABTS approach yielded a comparable result, with antioxidant activity around 1.33 times greater for the 3% iceplant salty biscuits (Figure 1).

Hassan (2023) observed that salty biscuits enriched with sting nettle have strong antioxidant activity because of the presence of high levels of phenolic components. As a result, the increase in antioxidant activity of salty biscuits enhanced with iceplant in this study could be attributed to the high levels of total phenols and total flavonoids in the iceplant powder, as well as the production of Maillard reaction products throughout bakery processing, as reported by Žilić *et al.* (2021).

Table 5 shows the mineral compositions of salty biscuits containing 1.2 and 3% of iceplant and iceplant powder. The table also included salty biscuits with 1.2% iceplant, which is equivalent to replacing all of the salt in the control formula. Iceplant powder constitutes huge amounts of minerals, including magnesium, calcium, potassium, phosphorus, iron, zinc, and manganese (Table 5). Rodríguez-Hernández and Garmendia (2022) reported similar findings.

When 1.2% iceplant powder (rather than 1.2% salt) was added to salty biscuits, the amount of sodium was significantly reduced (P < 0.05) by more than 85.61%. Regarding the other minerals, there was no statistically significant (P < 0.05) variation in the iron, zinc, and manganese levels of salty biscuits containing 1.2% iceplant compared to the control group. However, there were notable variations (P < 0.05) in the amounts of sodium, calcium, potassium, phosphorus, and magnesium compared to the control. All minerals, except iron, zinc, and manganese, significantly increased (P < 0.05) with the addition of 3% iceplant powder. The amount of minerals was less than 15% of the daily necessary levels, except for iron, which

Table 5. Mineral composition and NaCl content of salty biscuits with 1.2 or 3% of iceplant powder.

Elements	15% of the Recommended Daily Values	Iceplant powder	Types of salty biscuits		
			Control	1.2% iceplant powder	3% iceplant powder
Na	750	3498[a]	769.51[b]	110.72[d]	276.83[c]
Ca	120	2350[a]	19.92[d]	39.56[c]	57.07[b]
K	300	12450[a]	201.75[d]	209.62[c]	224.33[b]
P	105	518[a]	88.63[d]	93.17[c]	97.89[b]
Mg	56.2	647.5[a]	14.84[d]	19.23[c]	23.80[b]
Fe	2.2	7.59[a]	2.55[b]	2.60[b]	2.67[b]
Zn	1.6	4.26[a]	0.81[b]	0.83[b]	0.88[b]
Mn	0.4	10.18[a]	0.69[b]	0.70[b]	0.72[b]
NaCl	–	ND	1.9[a]	0.284[c]	0.702[b]

–, not detected.
Values followed by the same letter in each row are not significantly different at P < 0.05.

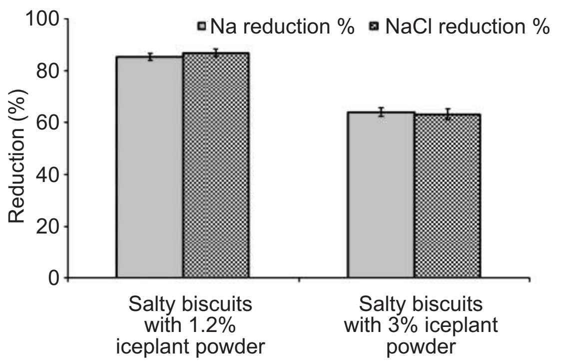

Figure 2. Reduction (%) of Na and NaCl contents of salty biscuits enriched with 1.2 or 3% of iceplant powder as salt replacer. Where, Reduction % = (control sample - treated sample/ control sample) × 100. Results are expressed as average ± standard deviation. Different uppercase letters correspond to significant differences (P < 0.05) between samples Na reduction%. Different lowercase letters correspond to significant differences (P < 0.05) between samples NaCl reduction %.

is greater, according to data in the same table. However, compared to the control, the sodium levels of these salty biscuits were lower (64.2% reduction).

According to data presented in Figure 2, using 1.2% iceplant powder as a salt replacement during the preparation of salty biscuits caused a reduction in Na and NaCl by 85.61 and 86.94%, respectively. Meanwhile, using 3% iceplant powder as a salt replacement resulted in the reduction of Na and NaCl by 64.2 and 63.05%, respectively.

Conclusion

The incorporation of iceplant in salty biscuits increased their saltiness, spread ratio, and width values and decreased their weight and thickness. Furthermore, the addition of iceplant powder to salty biscuits reduced the L*, hardness, and fracturability values of biscuits and enhanced their nutritional profile. This included improvements to chemical composition, phenolic and flavonoid contents, antioxidant activity, and mineral content, with high concentrations of calcium, potassium, phosphorus, magnesium, and iron in the biscuits. Salty biscuits with 3% iceplant powder were the most widely accepted compared to others that contained iceplant powder. However, replacing 1.2% NaCl with an equal quantity of iceplant results in an 85.61% sodium content reduction, which contributes significantly to lowering the overall NaCl content of the diet. Hence, iceplant powder is a promising salt replacer that can be used in food processing.

Authors' Contributions

Elsebaie Essam Mohamed contributed to the conceptualization, data curation, formal analysis,investigation, methodology, validation, writing of the original draft, and review and editing of the manuscript.

Suha Hashim Abduljawad contributed to data curation, formal analysis, methodology, software, and preparing the original draft. Marwa A. Sheir was involved in data curation, methodology, software, validation, and writing, review, and editing of the manuscript. Esmail Galal Boriy contributed to data curation, investigation, methodology, software, validation, and writing the original draft.

Conflicts of Interest

All authors declare no conflict of interest.

Competing Interests

All authors declare no financial or nonfinancial competing interests.

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Data Availability Statement

Data available on request due to privacy or ethical restrictions.

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