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Chemical, rheological and sensory characteristics of wheat bread enriched with chia (*Salvia hispanica* L.) seed gum

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ABSTRACT

Bread is a staple food in many countries worldwide. The aim of this study is the presentation of a novel type of bread prepared of wheat flour and extract of chia seed gum (CSG). The CSG was included in the wheat flour mixture in a concentration from 2 to 10%. The flour mixture was characterized by its rheological properties through amylography, farinography, and extensography tests. The bread was also subjected to texture, color, and tactile analysis. The highest grades of the bread in terms of appearance, flavor, aroma, texture, and color were shown for flour mixture that contained 10% of CSG ($p < 0.05$); namely, this wheat mixture showed an improved value of volume, specific size, external and internal characteristics of bread.

1. Introduction

Chia (*Salvia hispanica* L.) is one of the herbal plants with serrated leaves and blue flowers. Chia seeds (CS) have been consumed by humans since ancient times, particularly by the Aztecs and Mayans in the Central American regions. However, they disappeared for a long period. In recent years, there has been a re-discovery of the nutritional benefits and health-promoting functions of chia seeds. (Knez Hrnčič et al., 2020, Din et al., 2021, Rahman et al., 2017). Namely, chia seeds are a great source of nutrients like proteins, oils, soluble fibers and many other bioactive compounds such as phenolic and antioxidants (Romankiewicz et al., 2017, Adamczyk et al., 2021). They have gained great interest from researchers due to (i) the increased global desire towards healthy lifestyles, and (ii) increasing incidences of chronic diseases associated with gluten-containing foods. The use of chia seeds has also been led by its health-promoting benefits in diseases such as high blood pressure, diabetes, and cholesterol due to its antioxidant properties (Din et al., 2021, Nduko et al., 2018, Oliva et al., 2021, Enes et al., 2020). The Food and Agriculture Organization (FAO) of the United Nations described chia seeds as an important source of polysaccharides by a relatively high content of dietary fiber (38–40 g/100 g as they contain 3–6% gum, that can hold water 27 times of its weight (Khoury et al., 2023, Zięć et al., 2021, Eker & Karakaya, 2020). In the food industry, natural gums are preferable due to their biodegradability and biocompatibility with nontoxic impact on human health as well as lesser impact on the environment.

Chia gum extracted from chia seeds is a white powder, which when dissolved in water even at low concentrations forms a highly viscous solution - it is highly desirable as a stabilizer as a foam, emulsifier or binder in food and baked goods. Chia seed gum (CSG) has also been used as a replacement of eggs or oil in cakes, making it vegan and vegetarian friendly (Segura-Campos et al., 2014, Atik et al., 2020, Masood, 2022). In addition, gums can also be obtained easily from various sources and in large quantities for easy production and at low cost (Masood, 2022, Bhosale & Osmani, 2014, Goswami & Naik, 2014, Rani & Murthy, 2014, Karmakar, 2016). Moreover, gum has been used as an additive in the baking industry to modify rheological properties. For example, it improves the qualitative evaluation of bread by enhancing the structural properties of wheat dough with the addition of gum and improving the quality of baked goods. (Giaretta et al., 2018, Elhassaneen et al., 2014).

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In addition, the colloids affect the glutinous network of the bonds in the dough and thus improve the physical-elastic properties; for example, the bread has a larger volume, better porosity and a desirable pulp texture (Das et al., 2013). Gums are hydrophilic vegetable colloids while gels are a sticky mass. Gels are usually found in different parts of plants, leaves, seed coats, roots and barks; they are translucent materials, polymers of monosaccharides or mixtures of monosaccharides, many of which are associated with uronic acid (Al-Shammari et al., 2019, Deogade et al., 2012, Farooq et al., 2015, Choudhary & Pawar, 2014).

CSG gum exhibits health-enhancing properties, including hypoglycemic, antimicrobial, and immunostimulating effects, attributed to its polysaccharides. These polysaccharides contain dietary fiber, which promotes intestinal health, improves bowel movement, prevents constipation, and enhances overall digestive function (Adamczyk et al., 2021). Additionally, consuming whole grain breads rich in fiber and seeds, along with a high intake of omega-3 fatty acids, can aid in reducing blood cholesterol levels and mitigating the risk of cardiovascular diseases.

The objective of this study is to explore the chia seeds as available low cost plant sources of gum and to study their physicochemical properties. Also, the effect of CSG incorporation on the quality of conventional bread made out of wheat flour is considered through the evaluation of the rheological properties of the flour mixture and its sensory characteristics. Incorporation of a small amount of CSG as a wheat flour substitute in the formulation of bread can yield positive effects on its technological parameters.

2. Materials and methods

2.1. Materials

In this study, chia seeds (*Salvia hispanica* L.) were purchased from the local market of Basrah City, Iraq, and they are used for the extraction of CSG. Ethanol, Arabic gum, and all other chemicals and standards used for gum extraction and comparison purposes are of analytical grade and purchased from Merck Sigma-Aldrich (St. Louis, MO, USA). Wheat flour was obtained from the General Company for Grain Processing Basrah, Iraq, consisting of 15% Australian wheat, 15% American wheat, and a 70% mixture of local wheat from Iraq. Flour was stored in polyethene bags at 4 °C until its use.

2.2. Extraction of the chia seed gum

Chia seeds were thoroughly cleaned from dust and other particulate matter by deionized water and then ground using a grinder (MX-KM5070, Panasonic, Malaysia) based on the method previously described by Naji-Tabasi et al. (Naji-Tabasi et al., 2016). About 200 g of grounded chia seeds were added to the distilled water (seed-to-water ratio of 1:20 w/w) and mixed using a hot magnetic stirrer at 80 °C for 2 h in order to obtain a sticky mixture. The mixture was passed through a 200 µm sieve and then filtered by mixing with three volumes of 96% ethanol to precipitate the CSG. The precipitated gum was dried in an oven at 30 °C for 24 h. The dried powder was stored at 4 °C prior to further use.

2.3. Measurement of physical and functional properties

One gram of CSG was dissolved in distilled water (1% w/v) to obtain a dispersion. Its pH was determined by using a digital pH meter (pH-EMCO-256071, Japan) while the viscosity of the dispersion was measured using an Ostwald viscometer (size D, Thomas XXX80B1539, China), both measured at 25 ± 2 °C. To measure the viscosity, first, a relative density bottle was used to calculate the density of the dispersion. Next, the Ostwald viscometer was filled with the dispersion, and the time was recorded. The viscosity of the dispersion was calculated using Eq. (1):

$$\eta 2/\eta 1 = \sigma 2 - t2/\sigma 1 - t1 \tag{1}$$

where, η2 = viscosity of sample, η1 = viscosity of water, σ2 = density of sample, σ1 = density of water, t2 = time taken by the sample, and t1 = time taken by water.

The refractive index of the 1% w/v dispersion of CSG in water was measured using an Abbe Refractometer (A87117, Bellingham, UK) at 25 ± 2 °C. Data are presented as the average ± standard deviation of five measurements.

The bulk density of the CSG powder was measured according to the method described by Joshi et al. (Joshi et al., 2011). Namely, five grams of CSG powder was transferred to a 100 mL graduated cylinder with a lid; then the cylinder was mounted on a shaker and agitated for 10 min. The weight and volume of the CSG powder were noted; the bulk density was calculated using Eq. (2) and expressed as g.cm^{-3}.

$$Bulkdensity = Weightofpowder/Volumeofpowder \tag{2}$$

Water holding capacity (WHC) was estimated according to the method described by Sciarini et al. (Sciarini et al., 2009) with some modifications. Briefly, 0.1 g CSG powder was weighed in a test tube and 20 mL distilled water was added to it, the mixture was magnetically stirred at room temperature for 2 h. The test tube was left undisturbed overnight to complete hydration at room temperature. Later, the tubes were centrifuged at 1000 rpm for 10 min and the swollen sample was weighed after the supernatant was removed. Oil holding capacity (OHC) was conducted using the same method as the one described for WHC. Both WHC and OHC were calculated and expressed as g/g using Eqs. (3) and 4, respectively:

$$WHC = Ws - Wo/Wo \tag{3}$$

$$OHC = Ws - Wo/Wo \tag{4}$$

where, Ws = weight swollen sample (g) and Wo = weight dry sample (g).

Swelling index (SI) was determined by mixing 1 g of the CSG powder in a centrifuge tube with 25 mL of distilled water using a vortex electric mixer every 10 min for 1 h and then the tube was left undisturbed for 24 h at room temperature. To calculate SI, the volume occupied by the CSG powder before and after swelling was recorded and calculated using Eq. (5):

$$SI = [Vt - Vo/Vo] \times 100 \tag{5}$$

where Vo is the initial volume of the powder in a graduated cylinder and Vt denotes the volume occupied by the swollen gum after 24 h.

2.4. Rheological properties of the dough

The rheological characteristics of the dough for flour were evaluated in an amylograph (Brabender, model 800,250, Germany) according to AACC 22–10 (2000) method, farinograph (Brabender, model 810,161.001, Germany) according to AACC 54–21 (2000) method, and

Table 1
. Mixtures (w/w) of wheat flour and chia seed gum.

Samples	Wheat flour (%)	Chia seed gum (%)
T1	98	2
T2	96	4
T3	94	6
T4	92	8
T5	90	10
Control	100	0

an extensograph (Brabender, model 860,723, Germany) according to AACC 54–10 (2000) method (AACC 2000). Table 1 presents the tested mixtures prepared of wheat flour and CSG.

2.5. Bread formulation

The formulation and a loaf-making method proposed by Mikulec et al. (Mikulec et al., 2019) were applied in this study. Namely, bakery dough was prepared using a single-phase method (Mikulec et al., 2019) with some minor modifications. Table 2 presents the main components of the mixture. The CSG extract has been added as a substitute to the wheat flour in amounts of 2%, 4%, 6%, 8%, and 10% CSG. The control sample (C, 0%) was wheat bread prepared from wheat flour without the addition of CSG. After mixing and kneading all ingredients, the dough was left to ferment for 40 min at 30 °C and 70–80% relative humidity in a proofing chamber. The weight of each piece of dough is 100 g, each dough was prepared in triplicate. The dough was formed and placed in aluminum pans 230 mm x 100 mm x 40.5 mm. After the fermentation (45 min, 30 °C, 89% relative humidity), the bread was baked in a Modex (OV9600UK) batch oven at 200 °C for 40 min.

2.6. Baking test

Sensory evaluation of baking was performed on 44 consumer habitual bread subjects (18 men and 26 women, 18–58 age). Volunteers were recruited from the staff and students at the College of Agriculture/ Department of Food Science at Basrah University, Iraq, and they are from different socioeconomic backgrounds. Consumer tests have been performed in individual booths in the Grain Chemistry and Technology Laboratory.

2.7. Statistical analysis

The results were analyzed statistically using a one-way analysis of variance. Duncan's multiple range test was applied to calculate the significant differences with $p < 0.05$ by means of CoStat software (Monterey, CA, USA, version 6.4).

3. Results and discussion

3.1. Physical and functional properties of extraction gum

Physical properties such as viscosity, swelling index, bulk density, pH, refractive index, and functional properties WHC and OHC of CSG were evaluated and compared to Arabic gum; obtained results are presented in Table 3. CSG had a pH of 6.30, which is above the isoelectric point, as it is a neutral polysaccharide compared to Arabic gum, which has a pH of 5.02. It is also noted the viscosity profiles of CSG dispersion; showed a non-Newtonian behavior, with a registered viscosity of 58.32 cP while Arabic gum showed a lower viscosity of 3.18 cP. Namely, the viscosity of CSG is higher than the corresponding values of other gums used in the food, pharmaceutical and cosmetic sector like locust bean gum, guar gum, tragacanth gum, and ghatti gum (Segura-Campos et al., 2014, Parija et al., 2001, Yanti & Ali, 2017). The results also indicated that the refractive index of CSG is 1.3337 which is lower than the refractive index of Arabic gum 1.3335. The reason for this discrepancy could be due to several factors such as the number of atoms in the molecule, arrangements of the atoms, how they are related to each other, and the type/number of bonds. The WHC of CSG was 50.13 g/g gum while it is lower for Arabic gum 13.24 g/g. That higher value of WHC for CSG is a good option in terms of modification of the physical properties of food products as well as for emulsion stabilization (Timilsena et al., 2016). In terms of OHC, which is attributed to the physical entrapment of oil by molecules such as lipids and proteins, CSG showed a value of 15.57 g/g which is higher than the corresponding value for Arabic gum 7.11 g/g. This is also confirmed by other authors; similar values were found by Felisberto, et al., (Felisberto et al., 2015) 12.97 g/g and by Segura-Campos, et al., (Segura-Campos et al., 2014) 11.67 g/g. Moreover, the CSG showed a higher swelling ratio 54.32% than the swelling ratio of Arabic gum 0.22%; in agreement with Archana, et al., 35]. The bulk density of CSG 89.68 g/cm^3 is found to be lower than the bulk density of Arabic gum 128.06 g/cm^3.

Table 2
Ingredients for the bread formulation.

Ingredients	Weight (g)
Wheat flour	90–100
Chia seed gum	0–10
Water	Based on farinograph readings
Sugar	2
Fat	1
Dry yeast	2
Salt	1.5

Table 3
Physical and functional properties of chia seed gum and Arabic gum.

Parameter observation	Chia seed gum	Arabic gum
Viscosity (cP)	58.32 ± 0.01	3.18 ± 0.02
Bulk density (g cm^{-3})	89.68 ± 0.34	128.06 ± 0.09
Swelling index (%)	54.32 ± 0.17	0.22 ± 0.02
Refractive index	1.3337 ± 0.0001	1.3335 ± 0.0002
pH	6.30 ± 0.16	5.02 ± 0.02
Water holding capacity (g/g)	50.13 ± 0.02	13.24 ± 0.02
Oil holding capacity (g/g)	15.57 ± 0.21	7.11 ± 0.01

3.2. Rheological test

3.2.1. Farinograph test

The rheological properties of the dough are important from the point that they reflect the mechanical characteristics of the dough in addition to the quality of the final product. In general, it depends on the chemical composition of the flour and the nature of the added ingredients (Table 4). The viscoelastic of the dough can be observed under continuous mixing at a constant temperature. The water absorption rate increases with an increase in the added amount of CSG. Namely, when 2% CSG was added, the increase was to 60.17%, while with the addition of 10% CSG, the increase was 61.20% compared to the control value of 59.67%. The water absorption ratio means the amount of water added to the wheat flour from the first minute to make a dough, bringing the farinograph curve to 500 BU. The increased water absorption is due to the hygroscopic nature of the gum, and this is due to the presence of a large number of hydroxyl groups that interfere with water molecules (Mahmood et al., 2014).

The dough development time for the control sample was 2.50 min, while the highest dough development time was 8.30 min when 10% CSG was added to the flour mixture as the dough development time increased with the increase of the replacement amount. While there was a decrease in the stability of the dough with an increase in the replacement rates 6–10% compared to the control sample in which the stability time was 11.00 min; the highest dough stability time of 12.87 min was achieved when the replacement of 4% CSG was added to the flour mixture, and the least stability time was 7.20 min at the replacement rate of 10% of CSG. The decrease in dough stability is due to the decrease in the hydration rate of the compounds due to the increased competition for water binding between gluten proteins and the mucilage particles (Ahmed et al., 2020). Good quality bread dough has stability values ranging from 10 to 15 min (Aguirre et al., 2021, Tebben & Li, 2019). The results were consistent with what other authors found (Mohamed et al., 2022) when they studied the rheological properties of the dough to which different concentrations of ziziphus and cordia gums were added. Values of each degree of softening and quality number for the dough with added concentrations of 2–10% CSG ranged from 11 to 31

Table 4
Farinograph of dough prepared from wheat flour supplemented with chia seed gum.

Chia seed gum (%)	Water absorption capacity (%)	Development time (min)	Stability time (min)	Softening degree (Farinograph unit, FU)	Farinograph quality number (millimetres, mm)
0%	59.67 ± 1.69 ᵃ	2.50 ± 0.00 ᵇ	11.00 ± 0.82 ᵇ	14.00 ± 0.00 ᶜ	126.00 ± 4.08 ᵃ
2%	60.17 ± 2.09 ᵃ	6.70 ± 0.16 ᵃ	11.27 ± 0.17 ᵇ	11.00 ± 1.63 ᶜᵈ	124.00 ± 2.45 ᵃ
4%	60.00 ± 1.63 ᵃ	7.00 ± 0.82 ᵃ	12.87 ± 0.25 ᵃ	8.67 ± 1.70 ᵈ	130.00 ± 0.82 ᵃ
6%	60.70 ± 0.16 ᵃ	7.70 ± 0.08 ᵃ	9.10 ± 0.16 ᶜ	22.00 ± 1.63 ᵇ	106.00 ± 4.89 ᵇ
8%	61.00 ± 0.82 ᵃ	8.00 ± 1.63 ᵃ	8.00 ± 0.82 ᵈ	31.00 ± 1.63 ᵃ	99.33 ± 2.05 ᵇ
10%	61.20 ± 0.22 ᵃ	8.30 ± 0.24 ᵃ	7.20 ± 0.00 ᵈ	31.00 ± 2.45 ᵃ	52.67 ± 2.49 ᶜ

Presented values are mean ± standard deviation, $n = 3$. Presented values with the different superscript letters (within a column) are significantly different by Duncan's test ($p < 0.05$). A different lowercase letter in the same column indicate statistical significance.

(Farinograph unit, FU) and 52.67–124 (mm) compared to the control group 14 (FU) and 126 (mm), respectively.

3.2.2. Extensogragh tests

Energy is defined as the force needed to stretch the dough to the point of its rupture. The higher the dough energy values, the stronger the dough, this is related to the quantity and quality of gluten in the dough and good gas holding capacity in the final product. The strength of the dough is measured by the area, cm^2, under the extensograph curve - it represents its elasticity and extensibility (Mahmood et al., 2014, Ammar et al., 2016). In this work, the highest energy was obtained during the rest time of 45, 90, and 135 min in the dough in which wheat flour was replaced with 4% CSG, 128, 140, and 123 cm^2, respectively (Table 5). The lowest value was observed in the flour mix replaced with a concentration of 10% of CSG during the studied rest time 80, 94, and 99 cm^2, respectively, compared to the control containing wheat flour-free 104, 101, and 103 cm^2, respectively.

When the sample of flour was replaced with a different concentration of CSG, the resistance increased with an increase of the CSG addition from 2 to 10%, as the resistance value after 135 min of rest reached 753 and 653 BU, after it was 45 min 479 and 418 BU in the dough with replacement rates 10% and 8% of CSG, respectively. In the dough replaced with 2% and 4% of the CSG, the resistance values after 45 min it was 290 and 320 BU, respectively, while after 135 min of rest, it reached values of 506 and 556 BU, respectively, compared to the control in which the resistance values after the studied rest time reached 225, 354, and 457.33 BU, respectively.

As for the elasticity values, it is noted that their values decrease with the increase in the replacement effect, as it was found that the lowest value of the elasticity in the sample with 10% CSG after 45 and 90 min and they are of 148 and 122 mm to reach after 135 min to 103 mm, compared to the control sample in which the tensile values of 187, 161, and 135 mm for each studied rest time, respectively. The results showed the variation in the elasticity coefficient values during the studied rest periods at a 2% replacement ratio of 1.60, 2.57, and 2.90 compared to the control sample that performed 1.40, 1.80, and 2.32, respectively, while it was 3.30, 5.50, and 7.30 in the 10% replacement ratio at the rest time of 45, 90, and 135 min, respectively. The values between 2 and 4 are best and lower than 2 means the fluidity of the dough and higher than 4 means stiffness in the dough. The elasticity resistance reflects the extent of the dough's hardness due to the increased proportions of CSG while the elasticity measures the strength of the dough and the determining factor of quality and consistency of the final product. The elasticity and extensibility mean a complex balanced process starting with the mixing process and the development of the matrix gluten, which means the ability of the dough to stretch and return to the original shape. The desired quality of dough is the result of the combination of good resistance and elasticity (Rosell et al., 2001). The matrix dough consists of two phases, the continuous phase (the high molecular weight glutenin) contributes to the formation of disulfide bonds and this represents the properties of the elasticity while the second phase (the low molecular weight) gliading and this gives the viscosity gives occupying the gums, it is located in the discontinuous phase and contributes to the balance between the elasticity and extensibility of the dough as it has allowed molecular weight compared the high molecular weight of glutenin (Simsek, 2009). The long resting time results in a cohesive gluten network through the interactions between and inside the molecules. Adding gums to the wheat flour makes the dough less elastic due to the presence of fiber which causes a decrease in the elasticity values as a result of fiber competing with gluten to bind with water (Aguirre et al., 2021, Sudha et al., 2007, Wang et al., 2014). Hydrocolloids are high molecule weight, hydrophilic biopolymers that have many functions in the food industry, one of their most important features is their ability to

Table 5
Extensographic properties of dough prepared from wheat flour supplemented with chia seed gum.

Time (min)	Chia seed gum (%)	Energy (cm^2)	Resistance to extension (Brabender units, BU)	Extensibility (millimeters, mm)	Ratio number (BU / mm)
45	0%	104 ± 3.27 ᶜᴬ	225 ± 4.08 ᶠᶜ	187 ± 1.63 ᵇᴬ	1.40 ± 0.24 ᵈᴮ
	2%	116 ± 0.82 ᵇᶜ	290 ± 0.82 ᵉᶜ	196 ± 0.00 ᵃᴬ	1.57 ± 0.05 ᶜᵈᴮ
	4%	128 ± 1.63 ᵃᴮ	320 ± 0.00 ᵈᶜ	179 ± 0.00 ᶜᴬ	1.60 ± 0.08 ᶜᵈᶜ
	6%	104 ± 3.27 ᶜᴮ	348 ± 2.45 ᶜᶜ	176 ± 2.45 ᶜᴬ	1.97 ± 0.05 ᶜᶜ
	8%	102 ± 0.00 ᶜᴬᴮ	418 ± 1.63 ᵇᶜ	151 ± 1.63 ᵈᴮ	2.47 ± 0.34 ᵇᴮ
	10%	80 ± 0.82 ᵈᴮ	479 ± 0.00 ᵃᶜ	148 ± 3.27 ᴱᵃ	3.30 ± 0.24 ᵃᶜ
90	0%	101 ± 0.00 ᵈᴬ	354 ± 1.63 ᵉᴮ	161 ± 0.00 ᵇᴮ	1.80 ± 0.08 ᵈᴬᴮ
	2%	125 ± 1.63 ᵇᴬ	404 ± 3.27 ᵈᴮ	187 ± 1.63 ᵃᴮ	2.57 ± 0.26 ᶜᴬ
	4%	140 ± 4.08 ᵃᴬ	442 ± 1.63 ᶜᴮ	139 ± 7.35 ᶜᴮ	2.87 ± 0.05 ᵇᶜᴮ
	6%	107.33 ± 1.25 ᶜᴮ	441 ± 0.00 ᶜᴮ	157 ± 1.63 ᵇᴮ	3.17 ± 0.09 ᵇᴮ
	8%	101 ± 1.63 ᵈᴮ	488 ± 1.63 ᵇᴮ	194 ± 3.27 ᵃᴬ	3.23 ± 0.29 ᵇᴮ
	10%	94 ± 3.26 ᵉᴬ	673 ± 3.27 ᵃᴮ	122 ± 1.63 ᵈᴮ	5.50 ± 0.08 ᵃᴮ
135	0%	103 ± 2.45 ᶜᵈᴬ	457.33 ± 4.49 ᶠᴬ	135 ± 4.08 ᵇᶜ	2.32 ± 0.35 ᵈᴬ
	2%	121 ± 0.00 ᵃᴮ	506 ± 2.45 ᵉᴬ	164 ± 1.63 ᵃᶜ	2.90 ± 0.28 ᵈᴬ
	4%	123 ± 2.45 ᵃᴮ	556 ± 4.89 ᵈᴬ	129 ± 0.00 ᶜᴮ	4.03 ± 0.66 ᶜᴬ
	6%	116 ± 2.45 ᵇᴬ	579 ± 3.27 ᶜᴬ	118 ± 0.82 ᵈᶜ	4.43 ± 0.09 ᶜᴬ
	8%	104 ± 0.00 ᶜᴬ	653 ± 0.00 ᵇᴬ	125 ± 0.00 ᶜᶜ	5.40 ± 0.54 ᵇᴬ
	10%	99 ± 2.45 ᵈᴬ	753 ± 2.45 ᵃᴬ	103 ± 2.45 ᵉᶜ	7.30 ± 0.24 ᵃᴬ

Presented values are mean ± standard deviation, $n = 3$. Values with the different superscript letter (lowercase for different treatments 0%, 2%, 4%, 6%, 8%, and 10% at same time) and (uppercase for 45, 90, and 135 mins, at the same treatment) are significantly different by Duncan's test ($p < 0.05$).

control and regulate the texture and rheological properties of food. In the bakery industry, it is especially added to stabilize emulsions suspensions and foam also to improve manufacturing properties. Among other properties, it is able to delay starch degradation, retain moisture, improve the general composition, and increase the shelf life of food products (Eduardo & Svanberg, 2014, Qiu et al., 2015, Bojňanská et al., 2016).

3.2.3. Amylographic

The results in Table 6 present the gelatinization starting temperature of the substituted flour with 2% and 4% of CSG; they are 60.1 and 60.1 °C, respectively, compared to the control sample that has 62.6 °C, while the gelatinization starting temperature of the flour replaced with a concentration of 10% of the CSG was 61.5 °C. The gelatinization temperature reached 93.5, 89.6, and 89.6 °C for each of the flour of the control sample 0% CSG and the substituted sample mixtures with a concentration of 2% and 4% of CSG, respectively. The dough formation temperature depends on the concentration of starch while the gelatinization starting temperature is related to the nature of the interactions between the starch components (Švec et al., 2019). These differences due to a change in replacement ratios, which mean a change in the proportions of components such as proteins, fats, and fibers, are related to the process of solubilization and hydration of wheat flour starch. While the maximum gelatinization value in the flour sample of 10% of CSG was 1116 AU, in the control sample it was 746 AU, while in the flour replaced with concentrations of 2% and 4% of CSG, these values were 794 and 800 AU, respectively. Rodge, et al., (Rodge et al., 2012) showed that the optimum amylograph values are 300–650 AU, which indicates the optimum amylase activity and that products from this type of flour are very good technologically. When the maximum gelatinization values are above 800 AU, this means that the flour type has low amylase activity, the products made out of this type have very dry crumbs and are suitable for the manufacture of crackers with nice taste. Hence, hydrocolloids accelerated the gelatinization process and slowed down the retrogradation of starch. The maximum gelatinization value is an indicator of the ease of disintegrational starch granules and is often associated with the quality of the final products (Mandala et al., 2008).

3.3. Baking test

The results presented in Table 7 showed a decrease in volume and specific volume with an increase in replacement rates of 6 to 10% of CSG. The volume and specific volume of bread containing 10% replacement of CSG reached 6 cm^3 and 2.09 cm^3/g, respectively, while the highest volume and specific volume at the replacement rate is 4% CSG 9.03 cm^3, 3.31 cm^3/g compared to those of the control sample (8.00 cm^3, 2.82 cm^3/g). It was also observed that there was an increase in the volume and specific volume of 9 cm^3 and 3.10 cm^3/g, respectively, in the bread replaced with a concentration of 2% CSG. The high volume of bread is due to the gums containing a large number of hydroxyl groups that have the ability to bind with water by forming hydrogen bonds. The volume of bread is a very important characteristic, as it provides specialists with quality standards for the baking process. The increase in volume is a good indicator of economic aspects due to the increase in the refinement of the bread (Kohajdová & Karovičová, 2009). The volume gives an indication of dough gluten development and gas holding capacity (Hussain et al., 2022). Colloids such as gums can improve the volume of bread by the formation of hyolrophilic complexes with the ionic group and a glutinous network to the phenomenon of expansion under the pressure of fermenting gasses (Iglesias-Puig & Haros, 2013). The volume of the bread depends on the quality and quantity of the protein used in the dough mixers as well as the interactions with the starchy granules (Kowalski et al., 2020). The increase in the replacement rates of gums is offset by an increase in the values of the specific values to some extent as the decrease in the volume of bread occurs due to competition between gums and gluten for binding with water, which leads to a decrease in the available water and that the free water evaporates faster during baking compared to the formation of the gluten network, which results in a rapid gelatinization of the starch during baking and the pulp hardens early, but the gum cannot form a continuous network similar to gluten, which weakens the water retention, which leads to decrease in volume (Roberts et al., 2012, Zhang et al., 2019, Sivam et al., 2010). The increase in the volume of bread could be due to the interaction of the network of gum, which interferes with the gluten net. The hydrocolloids give a more porous structure to the gluten net, allowing for greater stability and greater expansion of the dough during fermentation (Bárcenas & Rosell, 2005).

The results of the external characteristics of the bread prepared by replacing wheat flour with a different concentration of CSG compared to the gum-free bread (control sample) are presented in Table 7. The crust color tends to darken more with the increase in the replacement rate compared to the crust color in the control sample, as the bread got a 10% replacement rate at the lowest score of 5.85, while no differences appeared in the 7.33 and 7.00 crust color characteristics between concentration 2% and 4%, respectively, while the control sample has a value of 7.09. The color is due to the Millard brown color reaction that occurs between amino acid and reducing sugars, while the increase in dark color can be due to the pigment in the extraction gum. It was also observed from the shape consistency of the prepared bread that there was no difference between the bread with replacement rate of 2% and 4% in addition to the control of 2.55, 2.55, and 2.55, respectively. The increase in the replacement rates reduced the strength of the gluten, which leads to the production of gas in an uneven and irregular manner, which increase is due to the occurrence of distortion and lack of consistency in the shape of the bread (Mahmood et al., 2014). The granularity of the crumb of bread, in addition to the taste and smell, is one of the internal characteristics of the bread, as the bread is of high quality when the volume of the bread as a crumb cell is small with thin homogeneous walls. It was obtained by bread with replacement rates of 2% and 4% of CSG compared to the control sample 8.75, 8.90, and 8.71, respectively. The lowest score of 7.09 was observed for bread with a percentage of 10% CSG. The color decreased with the increase in the replacement ratios of 2 to 10%; the control sample has the highest score of 9.18, while the bread with replacement ratios of 2% and 4% obtained a rating score of 9 (for both types of bread) and the bread with 10% CSG has the lowest score 7.

The bread replaced with CSG 2 to 6% obtained evaluation scores for aroma of 9.20, 9, and 8.60, respectively, and for taste of 12.60, 12.5, and 11.35, respectively, while in bread replaced with a concentration of CSG 8–10% for aroma were 8.45 and 8.20 respectively, and for taste 10.54 and 9.95, respectively. High levels of CSG may trap odor-causing volatile substances and restrict their interaction with taste buds and taste in addition the faint taste of CSG could be an important contributor to low odor consumer desire for bread replaced by certain concentrations of gum (Mahmood et al., 2014). From Table 7 can be seen that there is an

Table 6
Amylographic properties of dough prepared from wheat flour supplemented with chia seed gum.

Chia seed gum (%)	Gelatinization starts temperature (°C)	Gelatinization temperature (°C)	Maximum gelatinization (Amylograph units, AU)
0%	62.6 ± 0.24 [a]	93.5 ± 0.16 [b]	746 ± 4.89 [e]
2%	60.1 ± 0.16 [d]	89.6 ± 0.00 [e]	794 ± 2.45 [d]
4%	60.1 ± 0.08 [d]	89.6 ± 0.33 [e]	800 ± 0.00 [d]
6%	60.8 ± 0.08 [c]	91.4 ± 0.00 [d]	950.67 ± 4.64 [c]
8%	61.4 ± 0.24 [b]	93.1 ± 0.24 [c]	966 ± 4.89 [b]
10%	61.5 ± 0.41 [b]	114.1 ± 0.08 [a]	1116 ± 2.45 [a]

Presented values are mean ± standard deviation, $n = 3$. Presented values with the different superscript letters (within a column) are significantly different by Duncan's test ($p < 0.05$).

Table 7
External and internal characteristics of bread prepared from wheat flour supplemented with chia seed gum.

Parameters	Samples					
	Control	2%	4%	6%	8%	10%
Weight (g)	175.60 ± 0.24 e	183.80 ± 0.24 c	180.80 ± 0.08 d	191.40 ± 0.16 b	191.50 ± 0.29 b	192.60 ± 0.08 a
Volume (cm^3)	8.00 ± 0.00 ab	9.00 ± 1.63 a	9.03 ± 0.05 a	7.00 ± 0.00 bc	7.00 ± 0.08 bc	6.00 ± 0.00 c
Specific volume (cm^3\g)	2.82 ± 0.02 c	3.10 ± 0.04 b	3.31 ± 0.02 a	2.35 ± 0.02 d	2.19 ± 0.02 e	2.09 ± 0.04 f
Color crust	7.09 ± 0.02 a	7.33 ± 1.25 a	7.00 ± 0.00 ab	6.54 ± 0.04 ab	6.36 ± 0.02 ab	5.85 ± 0.02 b
Crust shape	2.45 ± 0.02 c	2.63 ± 0.02 b	2.85 ± 0.00 a	2.15 ± 0.01 d	2.00 ± 0.00 e	1.90 ± 0.01 f
Baking characteristic	2.50 ± 0.01 a	2.50 ± 0.00 a	2.50 ± 0.16 a	2.25 ± 0.02 b	1.89 ± 0.01 c	1.89 ± 0.03 c
Shape consistency	2.55 ± 0.04 a	2.55 ± 0.02 a	2.55 ± 0.01 a	2.25 ± 0.00 b	1.81 ± 0.02 c	1.81 ± 0.00 c
Cut and spread line	2.54 ± 0.00 a	2.54 ± 0.03 a	2.54 ± 0.03 a	2.35 ± 0.02 a	2.09 ± 0.02 a	2.42 ± 0.48 a
Granularity	8.71 ± 0.02 a	8.75 ± 0.01 a	8.90 ± 0.00 a	7.50 ± 0.41 b	7.40 ± 0.08 bc	7.09 ± 0.02 c
Crumb color	9.18 ± 0.02 a	9.00 ± 0.00 a	9.00 ± 0.24 a	8.18 ± 0.02 b	7.90 ± 0.00 c	7.00 ± 0.08 d
Aroma crumb	9.45 ± 0.04 a	9.20 ± 0.08 b	9.00 ± 0.08 b	8.60 ± 0.24 c	8.45 ± 0.04 c	8.20 ± 0.02 d
Taste crumb	12.45 ± 0.44 a	12.60 ± 0.16 a	12.50 ± 0.00 a	11.35 ± 0.01 b	10.54 ± 0.03 c	9.95 ± 0.02 d
Chewiness	8.72 ± 0.02 c	8.80 ± 0.00 b	8.95 ± 0.02 a	7.90 ± 0.02 d	7.80 ± 0.02 e	7.46 ± 0.01 f
Texture	12.63 ± 0.00 a	12.75 ± 0.04 a	12.57 ± 0.49 a	11.00 ± 0.00 b	10.95 ± 0.02 b	9.27 ± 0.06 c
Overall acceptable	86.55 ± 0.04 c	87.32 ± 0.02 b	87.68 ± 0.06 a	77.07 ± 0.06 d	67.19 ± 0.02 e	62.50 ± 0.33 f

Presented values with the different superscript letters (within a raw) are significantly different by Duncan's test ($p < 0.05$).

improvement in both the chewiness 8.80 and 8.95, and texture characteristics 12.75 and 12.57 of the bread replaced by 2% and 4% CSG compared to the respectively, the lowest evaluation score was in the bread substituted with 10% concentration of CSG in chewing and texture 7.46 and 9.27, respectively. Color is one of the most important sensory qualities that directly affect the consumer's affinity towards any food product, so great attention should be paid to the final color of bakery products to attract consumers (Salehi, 2020). The texture is the main contributor to the palatability and acceptance of bread by the consumer. Wang, Rosell and Benedito de Barber (Wang et al., 2002) concluded that increasing the dietary fiber increases the hardness of the crumb bread, so adding a high concentration of gum has a negative effect on the external and internal qualitative characteristics of the bread. The increase in crumb hardness when CSG is incorporated is mainly due to the features related to the formation of the gluten network. The increase in mucilage leads to an imbalance in the gluten matrix and causes the structure of the crumb cell. Bread is a soft solid substance consisting of two phases, one of which is a liquid that is related to the air and the other is a solid phase that is related to the material of the gaseous cell walls. The solid phase is completely interconnected, so the weak gluten network produces bread with a denser and more closed crumb (Miles et al., 1985, Ring et al., 1987).

The importance in the texture of the bread replaced with 2–4% CSG to the strength of the gluten network is due to the interference of the gum molecules containing many hydroxyl groups contributing to the retention of the gas cell during fermentation and baking. It was found through the result that the highest degree of overall acceptance was obtained for the bread replaced with a concentration of 4% of CSG 87.68 followed by 2% of CSG 87.32 compared to the control 86.55, while the bread replaced with a concentration of 10% CSG has the lowest overall acceptance score of 62.50. The dough properties are critical in designing baked products with desired organoleptic properties (Hussain et al., 2022, Miranda-Ramos et al., 2020).

4. Conclusions

The improvement of bread properties was observed by the substitution of wheat flour with CSG. The modifications of the novel bread mixtures can be linked with the effect of hydrophilic compounds of chia, like a good water absorption ability, and it can develop stable hydrocolloids and improved gluten net in the novel product. The results concluded that the substitution scores can reach 6% of added CSG gave the best results. In addition, this study can be used to improve not only the provision of nutrition but also to improve the technological characteristics of wheat flour. More studies are needed to assess consumer acceptance of modified bakery products such as bread. Bread with added CSG has a higher nutritional value and could be used as a functional food product. The processability of wheat dough with added CSG depends on the amount of added CSG because the dough's softness and stickiness increase with increasing the gel properties and therefore the improved water content.

Ethical statement - studies in humans and animals

The authors declare that they have did not conduct any studies in humans and animals.

CRediT authorship contribution statement

Rawdah M. Al-Ali: Conceptualization, Data curation, Formal analysis, Investigation, Software, Writing – original draft, Validation, Visualization, Funding acquisition. **Orass T. Al-Ibresam:** Conceptualization, Resources, Writing – original draft. **Sawsan A. Al-Hilifi:** Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Validation, Writing – review & editing, Writing – original draft, Project administration, Funding acquisition, Supervision. **Anka Trajkovska Petkoska:** Conceptualization, Data curation, Writing – review & editing, Project administration, Supervision. **Sameh A. Korma:** Conceptualization, Data curation, Formal analysis, Software, Investigation, Writing – review & editing, Project administration, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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